TOOELE
ARMY
DEPOT

FINAL

SYSTEM NON-OPERATION TEST PROPOSAL

IMPLEMENTATION OF ALTERNATIVE MEASURES INDUSTRIAL WASTE LAGOON

TOOELE ARMY DEPOT TOOELE, UTAH

Contract No. DACW05-00-D-0010
Task Order No. 7

Prepared for:

U. S. Army Engineer District, Sacramento
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OCTOBER 2003

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ACRONYMS AND ABBREVIATIONS

ASTM	American Society for Testing and Materials
bgs	Below ground surface
BRAC	Base Realignment and Closure
CDQMP	Chemical Data Quality Management Plan
CERCLA	Comprehensive Environmental Restoration, Compensation, and Liability Act
DSHW	Division of Solid and Hazardous Waste
EPA	U.S. Environmental Protection Agency
EVS	Environmental Visualization System
FFA	Federal Facilities Agreement
ft	Feet
ft/day	Feet per day
gph	Gallons per hour
gpm	Gallons per minute
hp	Horsepower
IWL	Industrial Waste Lagoon
kg	Kilogram
µg/L	Micrograms per liter
mg/L	Milligrams per liter
ml/min	Milliliters per minute
NOAA	National Oceanic and Atmospheric Administration
O&M	Operation & Maintenance
QA/QC	Quality Assurance/Quality Control
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facility Investigation
SOP	Standard operating procedure
SWMU	Solid Waste Management Unit
TCE	Trichloroethene
TEAD	Tooele Army Depot

ACRONYMS AND ABBREVIATIONS (cont'd)

UAC	Utah Administrative Code
UCL	Upper confidence limit
UDEQ	Utah Department of Environmental Quality
USACE	U.S. Army Corps of Engineers
VFD	Variable frequency drive
VOC	Volatile organic compound

1.0 INTRODUCTION

This System Non-Operation Test Proposal describes specific steps for conducting an experiment encompassing a period of reduced operation of the pump and treatment system at Solid Waste Management Unit (SWMU) 2, the Industrial Waste Lagoon (IWL) at Tooele Army Depot (TEAD), in Tooele, Utah. This Proposal has been prepared for TEAD and the U.S. Army Corps of Engineers-Sacramento District (USACE-Sacramento) under contract DACW05-00-D-0010 Task Order 7: Implementation of Alternative Measures, Industrial Waste Lagoon, Pump and Treat System, Tooele Army Depot, Utah. The primary objectives of the project are to initiate an interim operation mode during which groundwater pumping is reduced to a minimum level, and to conduct evaluations supporting development of an alternate program of plume management. An Alternative Measures Study will be developed once the evaluation is complete.

This proposal is the first task detailed in the Project Work Plan (URS, 2003). The purpose of the proposed test is to obtain information needed to assess how the existing groundwater treatment system exerts control on the groundwater plume by limiting the spatial extent of the plume and reducing measured levels of contamination. The evaluation period will extend for three years. During this period, the hydraulic behavior of the aquifer and contaminant concentrations will be closely monitored. During this period, hydraulic tests may be conducted to obtain improved estimates of aquifer conductivity and storage. Maintenance of the groundwater treatment system will continue, though on a modified schedule, both to protect the investment made by the Army in the system, and to ensure that it is operational should monitoring indicate that a resumption of operations is necessary.

Although the pump and treat system appears to contain the plume, the system may never meet the permit requirements to reduce groundwater contamination to specified levels by removing hazardous constituents from groundwater. Due to the nature of previous investigations and the decision to construct the system, the stability of the plume was not evaluated prior to active remediation, nor were alternatives other than pump and treat considered. Accordingly, a thorough evaluation of the effectiveness of the existing groundwater treatment system is necessary to support selection of an alternative remedy that may include development of a monitored natural attenuation remedy for groundwater and allow shut down of all or part of the existing groundwater treatment system.

This proposal falls under Module VI.A.3 of TEAD's Post Closure Permit (February 2002) under the Utah Department of Environmental Quality (UDEQ)-Department of Solid and Hazardous Waste (DSHW), which requires TEAD to submit a plan for additional measures to enhance the removal of hazardous constituents from groundwater. Activities in this proposal are intended to conform with TEAD's September 1991 Federal Facilities Agreement (FFA), the Comprehensive Environmental Restoration, Compensation, and Liability Act (CERCLA), the Resource Conservation and Recovery Act (RCRA), and the Utah Administrative Code (UAC) Sections R315-1 through 102, Hazardous Waste Management Rules, as applicable. Work will also be performed in accordance with other applicable Federal, State, and local regulations and guidance documents. The UDEQ and U.S. Environmental Protection Agency (EPA) perform regulatory oversight of the project.

1.1 TEAD AND THE IWL

TEAD was established in 1942 as the Tooele Ordnance Depot by the U.S. Army Ordnance Department; it was designated TEAD in August 1962. Originally, TEAD was a major ammunition storage and equipment maintenance facility that supported other U.S. Army installations throughout the western United States. The mission of maintaining and repairing equipment was discontinued in 1995. Currently, the missions of TEAD are to receive, store, issue, and maintain and dispose of conventional munitions.

TEAD is located in the Tooele Valley in Tooele County, Utah, immediately west of the City of Tooele and approximately 30 miles southwest of Salt Lake City (Figure 1-1). The installation occupies approximately 23,630 acres; 1,700 acres (from an original 25,173) were transferred to the Tooele City Redevelopment Agency in December 1998 under the Base Realignment and Closure (BRAC) program. It is bounded to the south by the Stockton Bar and South Mountain, to the north by Grantsville and the Great Salt Lake, to the east by Tooele and the Oquirrh Mountains, and to the west by the Stansbury Mountains.

The IWL is located in the eastern portion of TEAD (Figure 1-2). It was an unlined 400- by 200-foot evaporation pond that received wastewater from various industrial operations via unlined conveyance ditches. The lagoon was used for approximately 23 years, beginning in 1965, during

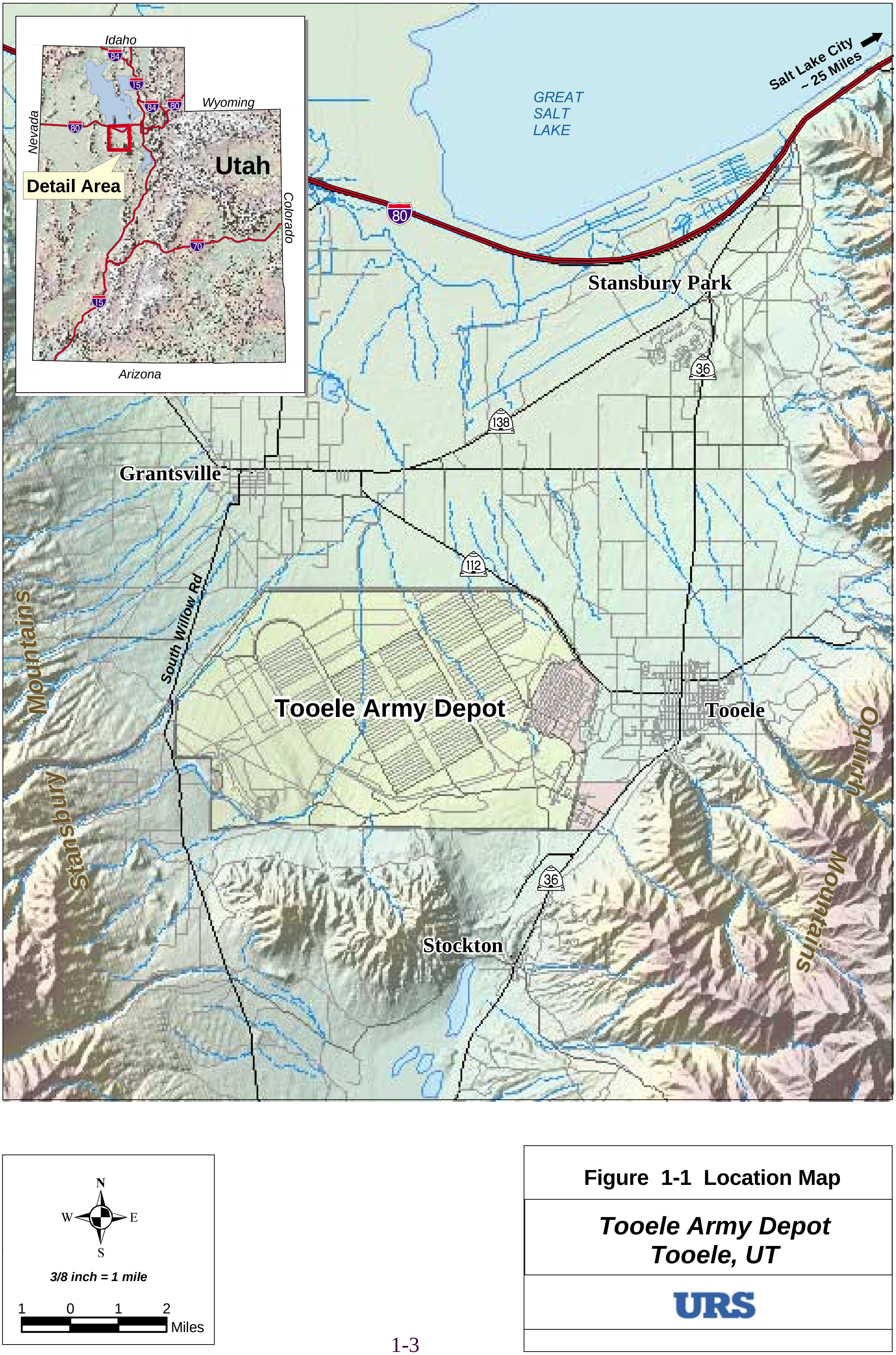

Figure 1-1 Location Map

Tooele Army Depot
Tooele, UT

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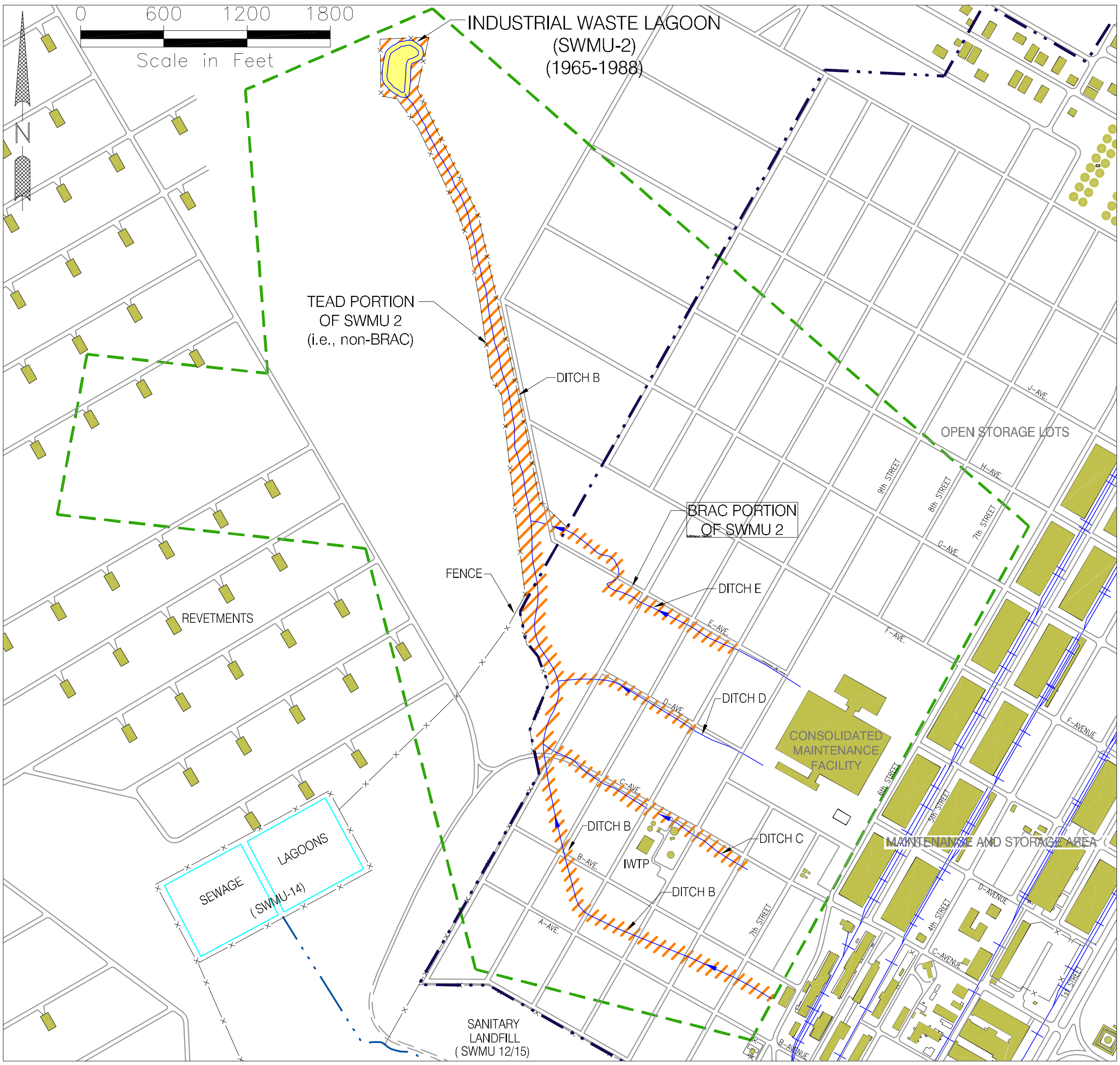

LEGEND

LAGOON CLOSED IN 1989 (i.e. LAGOON WATER PUMPED AND TREATED OFF-SITE. REMAINING SLUDGE SOLIDIFIED BY MIXING WITH SOILS REMOVED FROM IWL DITCHES. LAGOON THEN CAPPED WITH CLAY AND SYNTHETIC LINER)

1985 SAMPLING TRENCHES 1-7.
TRENCH LOCATIONS ARE APPROXIMATE AND BASED ON FIGURE C-1 OF JMM, 1986.

DRAINAGE DITCH ASSOCIATED WITH SWMU 2

FENCE

IWL SOILS EXCAVATED TO 12 FEET IN 1989

IWL SOILS EXCAVATED TO 20" AND CAPPED W/IMPERMEABLE SYNTHETIC LINER IN 1989

SWMU BOUNDARY (APPROX.)

BRAC BOUNDARY

SOURCE: RUST E&I, 1995

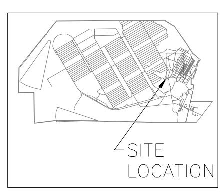

FIGURE 1-2
INDUSTRIAL WASTE LAGOON
(SMWU 2)
TOOELE ARMY DEPOT

URS

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which an average of more than 140,000 gallons of industrial wastewater and storm water were discharged daily until November 8, 1988. The subsurface soil and sludge in the IWL and ditches were determined to contain numerous contaminants thought to have originated in the wastewater stream.

In 1988, soil was removed from 650-foot segments of two ditches to a depth of approximately 12 feet and disposed of at the IWL (Tooele Army Depot, 1996). A comprehensive cleanup for closure of the ditches and lagoon was completed in 1989. The cleanup consisted of the removal of contaminated soil from the ditches and its placement in the lagoon. The bottom of each ditch was covered with clay, an impermeable synthetic liner, and backfilled with clean soil. The lagoon was capped with clay, a synthetic liner, and clean soil. Both areas were revegetated. The lagoon and primary ditch were fenced and posted with signs designating the area as a hazardous waste site.

1.2 IWL PLUME AND TREATMENT SYSTEM

Contaminants discharged to the IWL have infiltrated to groundwater and contributed to a northward trending dilute plume (Figure 1-3). The long axis of the plume runs parallel to the groundwater flow direction, and is approximately 22,500 feet in length as defined by a 5 microgram per liter (µg/L) trichloroethene (TCE) contour. The plume is approximately 7,500 feet wide, defined by a 5 µg/L contour to the west and an assumed boundary to the east. The eastern extent is assumed because the IWL plume has commingled with a second plume identified as the Northeast Boundary Plume, also shown on Figure 1-3. The inferred size and shape of the IWL plume has changed over time due to fluctuations in concentration detected in wells near the perimeter, to differing interpretation by various investigators, and partly to the number and configuration of monitoring wells used to investigate the plume.

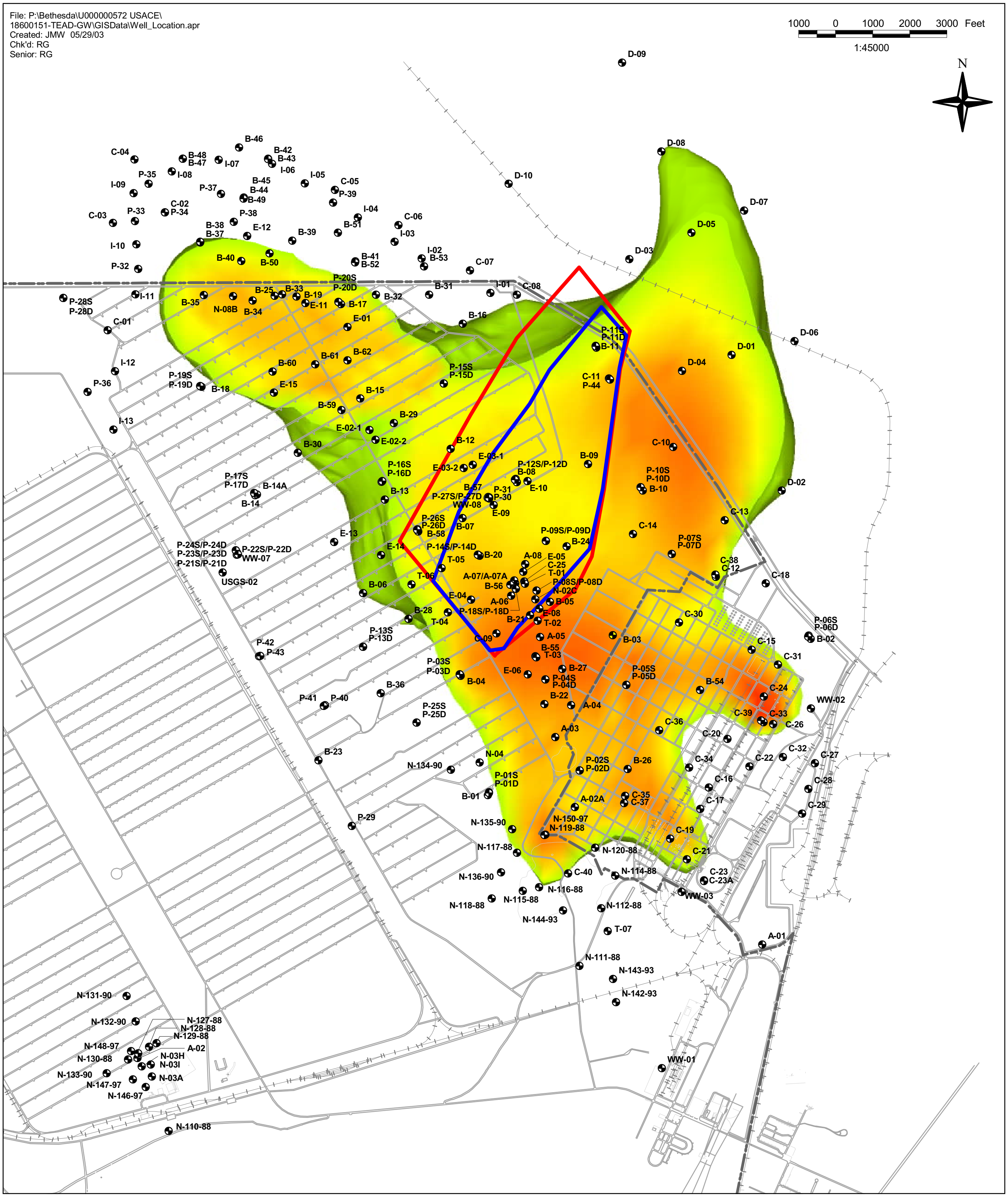
The predominant groundwater contaminant is the volatile organic compound (VOC) TCE, although other VOCs also have been detected. These include carbon tetrachloride, chloroform, benzene, ethylbenzene, toluene, 1,1-dichloroethane, and 1,1-dichloroethene, 1,2-dichloroethane, and 1,1,1-trichloroethane. The IWL plume originates in the southwestern portion of Tooele Army Depot's former Industrial Area. This area was transferred under Base Realignment and Closure (BRAC) and is no longer owned by the U.S. Army.

Other source areas of groundwater contamination have been identified in the former Industrial Area upgradient from the IWL and ditches and are under investigation as part of a RCRA Facility Investigation (RFI) being performed concurrently with the Alternative Measures Evaluation.

In late 1993 Tooele Army Depot began operation of an 8,000-gallon per minute (gpm) groundwater treatment system designed to contain and remediate the SWMU 2 contaminated groundwater plume originating from the IWL. The treatment system consists of 16 extraction wells, influent conveyance piping, treatment system, effluent conveyance piping, and 13 injection wells (Figure 1-4). A 50,000-gallon aboveground tank receives contaminated groundwater from 16 extraction wells via the influent piping system. Three 75-horsepower (hp) pumps transfer contaminated water from the holding tank to two air stripping towers. Each of the transfer pumps has a 4,000-gpm capacity (half of the design capacity). During normal operations, only two pumps are operational, while the third is held in reserve for backup purposes. Three 40-hp blowers generate the required vertical airflow in the stripping towers. Like the transfer pumps, each blower is designed for one-half of the design system load, with two operating under normal conditions, and one held in reserve.

Treated water from the stripping towers flows by gravity through the effluent conveyance piping to the 13 injection wells. The alignment of the extraction wells is generally along the main axis of the plume and the groundwater flow direction (Figure 1-4). The 13 injection wells are located in an arc at the downgradient leading edge of the plume. The injection wells were designed and located with the intent of controlling downgradient migration of the plume. The system is operated continuously, and is staffed full time.

The groundwater treatment system operates in accordance with requirements of TEAD's RCRA Post Closure Permit. This permit includes requirements for operation, maintenance, monitoring, reporting, and aquifer protection goals. The permit also requires numerical modeling of the groundwater plume, and annual recalibration of the model. Operation of the groundwater treatment system in its current configuration is a permit requirement. The permit currently sets the aquifer protection standards that the system must eventually meet at the maximum contaminant levels regulated under the Safe Drinking Water Act. There are, however, provisions for requesting modifications to the permit.



Well

Tooele Army Depot Boundary

TCE Plume, Sampling Event 370, Spring 2002 (TCE ≥ 5 µg/L)

Bedrock block as represented in layer 1 of 2003 groundwater model (4450 - 4500 ft)

Bedrock block as represented in layer 9 of 2003 groundwater model (3700 - 3900 ft)

TCE in groundwater µg/L

0.001 0.01 0.1 1 10 100

Figure 1-3
TCE in Groundwater, Spring 2002

Tooele Army Depot
Tooele, UT

URS

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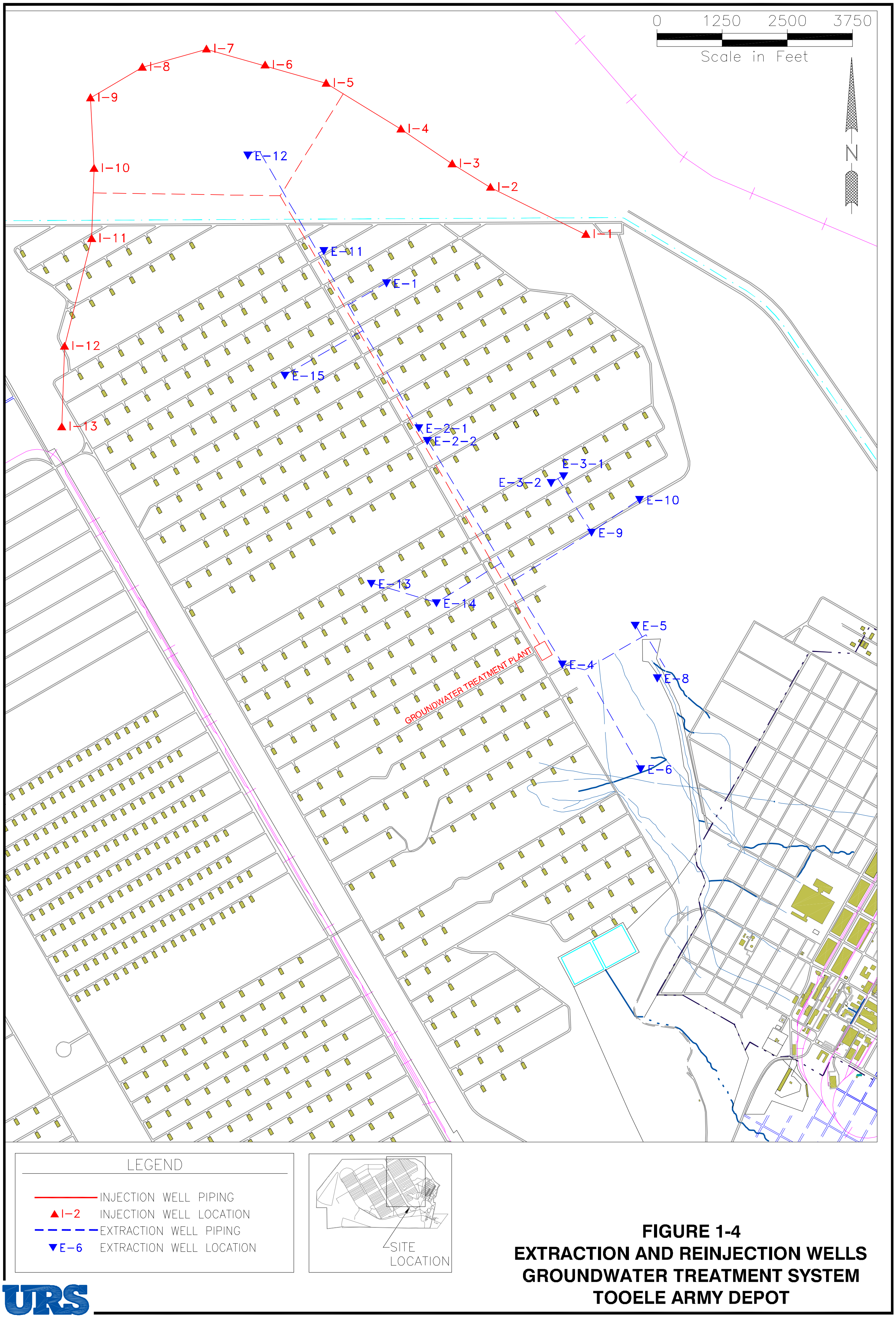

FIGURE 1-4
EXTRACTION AND REINJECTION WELLS
GROUNDWATER TREATMENT SYSTEM
TOOELE ARMY DEPOT

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1.3 TEST CONSTRAINTS

The stated objective of this test must be met within physical, operation, and regulatory constraints presented by the site. These constraints limit the design of the shutdown experiment, described in subsequent sections of this proposal. Consequently, the constraints are presented at the outset, and should be considered as the various recommendations for the 3-year test period are discussed. Two major issues affect all other aspects of the proposed program. First, any pumping at extraction wells that occurs during the non-operation test must be minimized to the extent practicable. Equipment constraints have a substantial effect on minimizing pumping. Second, all chemical data collected as part of the test must be of sufficient quality to be scientifically defensible, comparable to the baseline conditions, and independent in time.

Protecting TEAD's investment in existing equipment and appurtenances is paramount. Likewise, it is desirable to avoid costly temporary modifications to equipment during the test. As it presently exists, the equipment/operational constraints on the system are:

- Extraction wells, when operating, pump at a minimum rate of 100 gallons per minute (gpm).
- Transfer pumps at the treatment plant operate at a minimum rate of 1,500 gpm.
- Treatment system storage tank capacity is 50,000 gallons.
- Extraction wells without cathodic protection should operate no less frequently than every 90 days, such as E-12 at present; those with cathodic protection should operate no less than every 180 days. (All extraction wells are anticipated to have cathodic protection before the test begins.)
- Blowers can operate one at a time.
- Regular water flow through the stripper towers must be maintained to avoid cementation of the stripper tower matrix.

Physical modification of the equipment or investment in temporary equipment is not precluded, but nor is it desirable. This proposal is therefore developed without addition to or modification of equipment at the extraction wells.

Collection of adequate data prior to and during the test is imperative. Data quality and comparability will be assured by adhering to TEAD's Chemical Data Quality Management Plan (CDQMP) (USACE, 1999). Chemical concentration and groundwater elevation data are currently collected semiannually at TEAD. The baseline data control how data will be collected during the non-operation test. The major data collection constraints are:

- Shutdown should occur immediately following a semiannual monitoring event.
- Sampling should coincide with previous semiannual event dates to minimize the effect of seasonality when interpreting data.
- Sample locations should have an adequate spatial distribution to define the limits and internal character of the plume.
- Diffusive samplers require 2 weeks in the screened interval of a well to obtain chemical equilibrium.
- Samples must be temporally independent.

Every sampling event incurs substantial costs for analysis and sampling labor. Therefore, minimizing samples is an objective in developing the non-operation test plan.

1.4 PROPOSAL ORGANIZATION

The remainder of the proposal describes how the test will proceed within the aforementioned constraints. This System Non-Operation Test Proposal includes:

- Section 2.0—A recommended Shutdown Sequence describing the order in which extraction wells will be turned off, and the schedule on which the treatment plant will operate during the test period.
- Section 3.0--A Monitoring Plan to measure changes in water levels and contaminant concentrations in the aquifer during the test period.
- Section 4.0--An Alternative Pumping Strategy to reengage all or part of the groundwater treatment system should contaminant concentration increase at critical locations within the plume.
- Section 5.0—A System Maintenance Plan to identify requirements for maintaining treatment system equipment during the test period, including hardware, instrumentation, and electrical components of the system.

Together, these elements constitute a plan for reducing pumping, treatment, and injection of groundwater at TEAD to levels consistent with the objectives of a large aquifer rebound test, while at the same time preserving the operating capabilities of the groundwater treatment system.

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2.0 SHUTDOWN SEQUENCE

This section presents the recommended sequence for shutting off extraction wells. The plan is designed to maximize the duration of reduced pumping throughout the aquifer within the test period, while still protecting TEAD's investment through prudent exercise of the extraction and treatment equipment. This document does not present technical procedures for adjusting equipment during shutdown, which will be the role of the current operation and maintenance (O&M) contractor. Hydraulic and chemical monitoring will occur concurrent with and also after the shutdown, according to the schedules described in Sections 3 and 4.

2.1 SHUTDOWN CONSIDERATIONS

Two major factors affect the design of the sequence in which the extraction wells will be shutdown: the 3-year duration of the test, and the desire to obtain improved estimates of aquifer properties. Theoretically, extraction wells could be shut off simultaneously, one at a time, or, between these extremes, in groups. Shutting off extraction wells singly offers the greatest opportunity to investigate localized rebound behavior, and thus to obtain the most detailed information regarding aquifer hydraulic properties, particularly storage. If the shutdowns were spaced one month apart, however, over 1 year would pass before non-pumping conditions prevailed throughout the study area. Conversely, simultaneous shutdown maximizes the duration of test, which best meets the overall plan objective. However, it diminishes the ability to observe localized rebound, and thus to obtain local estimates of hydraulic properties. Therefore, group shutdown of wells is recommended to satisfy the objective of a long shutdown period, while still providing an opportunity for rebound data collection. In addition, group shutdown is consistent with an efficient program of system maintenance.

Improved understanding of the hydraulic character of the bedrock block is particularly important. Water level measurements (e.g., Kleinfelder, 2002), and numerical groundwater flow and contaminant transport modeling (HEC, 2003) indicate that the bedrock block and associated low-permeability faults exert major influence on groundwater flow. Large head gradients occur near the upgradient and downgradient boundaries of the bedrock, and the nature of the hydraulic connection between the bedrock block and surrounding alluvial sediments is a matter of high uncertainty. Therefore, extraction well shutdown will occur in two stages, as described below, in order to perform a rebound test in the bedrock block. The bedrock rebound test has two objectives: to provide information regarding the hydraulic connection between bedrock and alluvium, and to obtain data that can be used to infer hydraulic properties of the bedrock, especially storage.

2.2 RECOMMENDED SHUTDOWN SEQUENCE

The test period will begin with the concurrent shutdown of all extraction wells screened in bedrock, as detailed in Section 2.4. Water level rebound will be monitored in the bedrock block extraction wells and selected nearby monitoring wells, including wells screened in bedrock and wells screened in alluvium. (The monitoring program is fully described in Section 3.)

The remaining extraction wells will be shutdown 45 days after shutdown of the bedrock wells. The remaining wells will be turned off from north to south, i.e., from downgradient to upgradient, according to a schedule determined at the discretion of the treatment system O&M contractor to ensure smooth shutdown of the treatment plant and injection wells. Water level rebound will be monitored for 45 days in each of the remaining extraction wells and appropriate nearby monitoring locations.

The shutdown schedule described above was simulated using the most recent version of the TEAD groundwater flow model (HEC, 2003). The simulation was for a 3-year period to estimate the fraction of rebound that may occur after 45 days and three years. None of the aquifer properties in the model was modified. The simulation (more completely described in Appendix A) forecasts the following:

- Water levels in the bedrock block may rebound approximately 35 feet after three years.
- About 25 percent of the total rebound in bedrock occurs within 45 days after shutting down the bedrock block wells.
- Shutdown of the remaining extraction wells and the injection wells at the end of the 45-day bedrock rebound test has negligible effect on continued rebound within bedrock.

These forecasts depend on the aquifer properties currently assigned to the model. As mentioned previously, the storage characteristics of the groundwater system are particularly uncertain. Because the transient behavior of an aquifer depends on the ratio of hydraulic conductivity to storage (i.e., diffusivity), the preceding forecasts are likely to differ from observations.

Reconciling these differences, however, is one of the objectives of the bedrock block rebound test, because rebound data will the basis for improved estimates of hydraulic conductivity and storage. The observed rebound curves will act as new set of constraints on the model, which must be matched in order for the model to remain credible.

2.3 PERIODIC REDUCED PUMPING

After all extraction wells are shutdown, periodic exercise of the treatment system is necessary to verify that it is in working order, to reduce the potential for screen clogging and well corrosion, to keep anti-scaling treatment circulating in the treatment plant, and to identify any needed corrective maintenance.

Extraction wells are divided into two geographic groups for the purpose of periodic equipment exercise during the shutdown test, as shown in Table 2-1. Group 1 includes the six wells screened in the bedrock block (E-03-2, E-04, E-05, E-08, E-09, and E-10) and two nearby wells screened in alluvial sediments (E-03-1 and E-06). Group 2 includes those wells screened in alluvial sediments north and west of the bedrock block (E-01, E-02-1, E-02-2, E-11, E-12, E-13, E-14, and E-15). Each group will be turned on periodically as described in Section 2.4, and operated four days at the minimum practicable level, approximately 100 gpm (in contrast to current rates of approximately 100 to 750 gpm). Numerical simulation suggests that the low pumping rate and brief pumping duration are likely to have a negligible effect on the overall rebound in the aquifer, and thus will not compromise the primary objective of the test.

Table 2-1
Reduced Pumping Schedule

Pumping Group 1	Pumping Frequency	Pumping Group 2	Pumping Frequency
E-03-01	Day 90	E-01	Day 180
E-03-02	Day 270	E-02-01	Day 360
E-04	Day 450	E-02-02	Day 540
E-05	Day 630	E-11	Day 720
E-06	Day 810	E-12	Day 900
E-08	Day 990	E-13	Day 1080
E-09		E-14	
E-10	(180-day cycle)	E-15	(180-day cycle)

Note: 3 years equals 1095 days

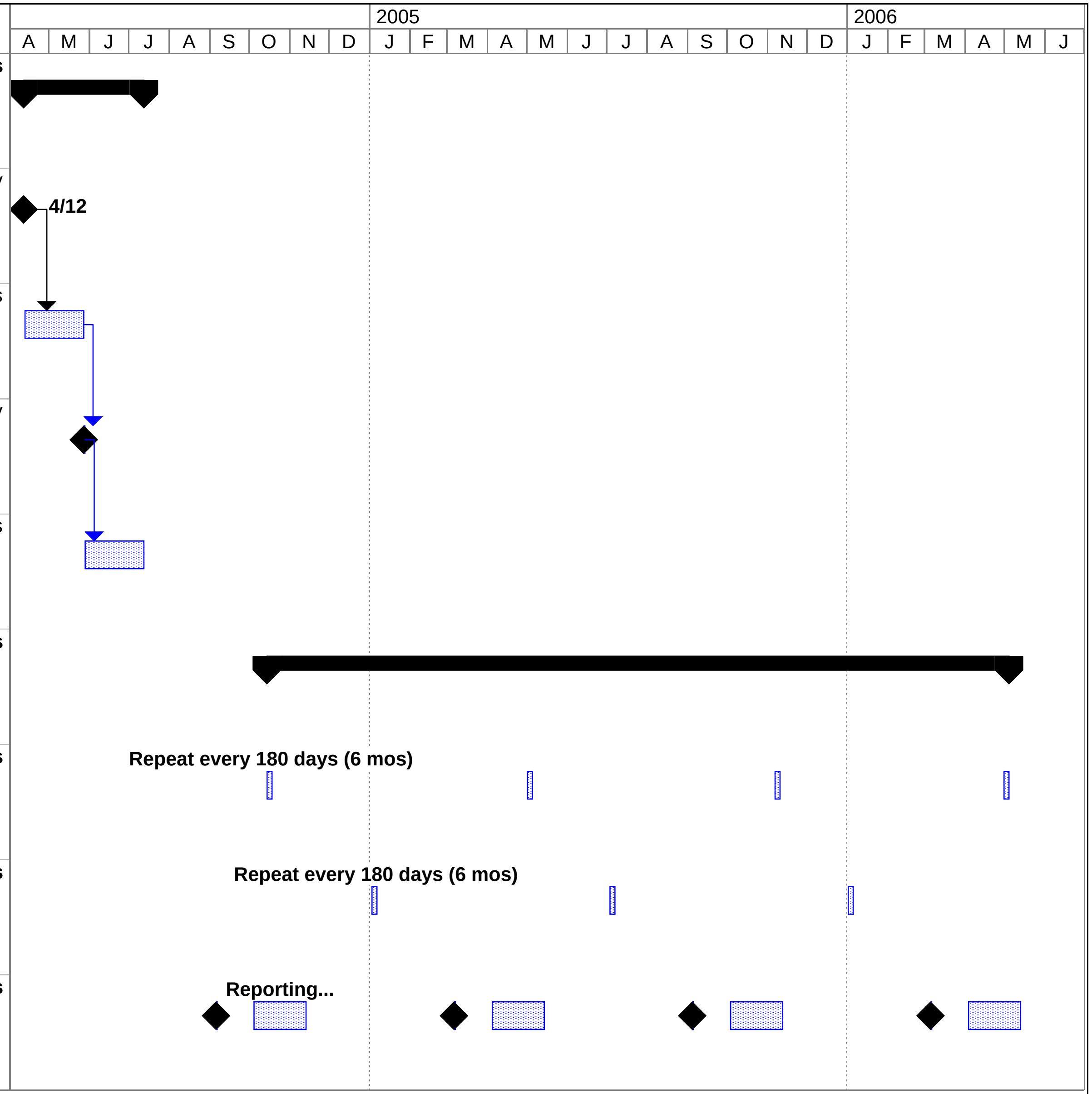
2.4 REDUCED OPERATIONS SCHEDULE

Following the protocol for maintaining the treatment system equipment (introduced in Section 1.3 and addressed in Section 5), each group of extraction wells will operate at the minimum pumping rate for four days. As shown in Table 2-1, each group will be exercised every 180 days, and no individual well will remain idle for longer than 180 days. (All extraction wells are expected to have cathodic protection at the start of the shutdown test. If not, adjustments to this schedule will be necessary to ensure that those wells without protection are exercised on a 90-day schedule.) The lag between the two group's cycles is 90 days, and is achieved by operating the first group of wells in reduced mode 90 days after the initial shutdown marking the start of the bedrock rebound test, and then operating each group on a 180-day cycle. This schedule reflects the 45-day delay between the initial shutdown of the bedrock extraction wells and the shutdown of the remaining wells, the need for the interval between operating periods for a well group to be no more than 180 days (to satisfy the constraint imposed by the cathodic protection system, Section 1.3), and the need to convey water in the treatment system lines every 90 days (to satisfy a regulatory constraint discussed in Section 5.3.3).

The shutdown and periodic equipment exercise schedule, summarized and illustrated in Figure 2-1, is as follows:

1. Day 1. Shut off extraction wells E-03-2, E-04, E-05, E-08, E-09, and E-10. Monitor groundwater elevation rebound in these wells and adjacent monitoring wells for 45 days (see Section 3).
2. Day 46. Shut off remaining extraction wells in the northern sediments (E-01, E-02-01, E-02-02, E-03-01, E-11, E-13, and E-14; E-12 is not currently operating) and southern well E-06. Monitor rebound in extraction wells and adjacent monitoring wells for 45 days. All extraction wells will be off at this time. Rebound toward natural conditions begins throughout the aquifer.
3. Day 90. Reduced operation of Group 1 extraction wells. Treatment system is operated for maintenance purposes at minimum levels for 4 days.

ID	Task Name	Duration
1	**Shut Down Extraction Wells**	**92 days**
2	Initial Shut Down (Bedrock)	1 day
3	Monitor for rebound	45 days
4	Shut Down (Remaining wells)	1 day
5	Monitor for rebound	45 days
6	**Maintenance Pumping**	**567 days**
7	**Pumping - Group 1 - Extraction Wells**	**567 days**
12	**Pumping - Group 2 - Extraction Wells**	**368 days**
16	**Semiannual Sampling**	**615 days**



Project: Reduced Operationsrev2 Figu
Date: Wed 10/29/03

Task | Progress | Milestone | Summary

Figure 2-1
Reduced Operations Schedule, IWL Tooele Army Depot

4. Day 180. Reduced operation of Group 2 extraction wells. Treatment system is operated for maintenance purposes at minimum levels for 4 days. Repeat on 180-day cycle.
5. Day 270. Reduced operation of Group 1 extraction wells. Treatment system is operated at minimum levels for 4 days. Repeat on 180-day cycle.

As presented in steps 4 and 5 above, each group of extraction wells will cycle through a 4-day period of reduced operation, both for routine maintenance purposes and to verify that the treatment system is in good working order and ready for use if required, while minimizing stress on the aquifer during rebound. Steps 4 and 5 will be repeated through the 3-year test period. During this time, TEAD will operate treatment plant in batch mode (see Section 5).

This schedule of periodic pumping achieves a balance between regular maintenance of system equipment and minimum stress on the aquifer during the 3-year, system-wide rebound experiment. The schedule may require minor adjustments to accommodate as yet unidentified aquifer pump tests, and unanticipated equipment maintenance and repair requirements.

2.5 PUMP TESTS DURING SYSTEM SHUTDOWN

It may be desirable during the 3-year test period to perform individual pump tests as part of a long-term plan for developing alternative measures for managing contaminated groundwater at TEAD. Candidate locations for such tests have not been identified, but will be chosen where improved estimates of aquifer properties are necessary. Locations may be chosen on the basis of rebound observations during the shutdown test. Provided that only a single well is pumped in a test and that tests are not closely spaced either spatially or temporally, individual tests can be performed without affecting overall aquifer rebound.

Any plans for pump tests will be developed in association with the regulatory overseers of this program.

3.0 MONITORING PLAN

This section presents the rationale behind selecting well locations and monitoring frequency for chemical and hydraulic monitoring during the reduced operations test. The test period serves as an experiment to learn whether contaminant mass within the plume is redistributed, and as an opportunity to observe groundwater behavior under non-pumping conditions.

The monitoring plan addresses two broad objectives. The first objective is to periodically assess the physical state of the groundwater system and the extent of contamination in groundwater. This objective can be met by continuing the semiannual monitoring program now conducted by TEAD, but with slight modifications to ensure that the spatial extent of groundwater contamination is adequately constrained. The second objective is to assess the effect of the groundwater treatment system on groundwater flow and levels of contamination in groundwater. This objective will be accomplished by carefully monitoring the response of selected wells during reduced operations of the treatment system. Both groundwater elevations and contaminant concentrations will be monitored. The monitoring well locations and their monitoring frequency are intended to measure the effects of reduced operation, and to estimate how the plume behaves while the treatment system is operated at reduced capacity.

Monitoring data will be of sufficient quality to evaluate alternative measures for managing groundwater contamination at TEAD. Data will be collected in accordance with the existing CDQMP developed for the TEAD (USACE, 1999) to ensure that data for future evaluation are comparable in quality to existing data. Table 3-1 summarizes how data needs were developed by jointly identifying the objective of the study and the decisions to be made using the data. Subsequently, the data types were identified within the defined temporal (the 3-year of the shutdown test) and spatial (the areal extent of monitoring well control) boundaries of the project. The plan is considered to be flexible enough to respond to future data collection needs, based on the evaluation of interim data results. These data development steps and how they relate to the reduced operation period are detailed in Table 3-1.

Table 3-1
Data Development Process

Data Quality Process Step	Contaminant Distribution	Hydrogeologic Information
Objective	Monitor groundwater VOC concentrations under minimal pumping conditions over a 3-year period.	Monitor groundwater elevations as they rebound to natural groundwater conditions under minimal pumping conditions over a 3-year period
Decision	What are the trends in contaminant concentration and static plume shape within key areas of the aquifer under minimal pumping?	How does groundwater behave under non-pumping conditions? Do data support modeling effects of isolated pumping?
Data Types	Chemical concentration data of similar quality to those measured immediately prior to shutdown.	Water levels measured in groundwater monitoring wells adequate to support groundwater modeling.
Project Boundaries	Consider behavior for 3 years in wells necessary to define plume(s).	Consider behavior for 3 years in wells necessary to define plume(s).
Results Evaluation	Test period data will be evaluated against historical concentrations. Statistics will determine the trends and variation of data over time for reduced pumping.	Test period data will be used to evaluate and enhance flow model calibration. Water level trends will be used to evaluate impacts of reduced pumping on the direction of plume migration over time.

Table 3-2
Data Types

Data Type	Objective	Data Location
Contaminant Distribution		
VOC concentration information at or near source locations.	To identify VOC transport/loading near sources	South of Bedrock near source areas
VOC concentration near Depot boundary	To identify VOC transport rates at boundary	On and Off Depot in the Northern Sediments
VOC concentration in wells within the plume body, non-bedrock wells	To ascertain plume shape and extent within local saturated sediments	On Depot in the Northern Sediments
VOC concentration in wells within the plume body, bedrock wells	To identify plume stabilization in local bedrock	IWL/Bedrock
Physical/chemical data	To evaluate the potential for natural attenuation	All sampled wells
Hydrogeologic Information		
Groundwater elevations during recovery	To compare storativity against that used in the flow model	Extraction wells and their nearby monitoring wells.
Groundwater elevations at full recovery	To identify natural groundwater levels within the plume and to determine local horizontal hydraulic gradients	Comprehensive wells throughout SWMU 2
Groundwater vertical flow	To determine vertical hydraulic gradients	Nested piezometers and well-pairs
Pump tests	To determine hydrogeologic characteristics	Bedrock block and other areas with uncertainty

3.1 DATA DEVELOPMENT

3.1.1 Data Types

Data will be collected throughout the 3-year test period. The data fall into two general categories: chemical parameters needed to characterize the contaminant distribution and hydrogeologic information (Table 3-2). The contaminant data should supply sufficient information to satisfy the objective of characterizing the nature and extent of groundwater contamination over the 3-year test period, including significant changes that occur during the test. Physical/chemical information such as pH, temperature, dissolved oxygen, oxidation/reduction potential, and conductivity will be useful to estimate the potential for natural attenuation of contamination. The hydrogeologic data will be used to characterize the state of the aquifer during the test, and are also expected to augment the data currently used to support numerical groundwater modeling efforts at TEAD.

Table 3-2 presents a matrix of data types that will be collected during the reduced operation period. This table also specifies the general data locations at which the data needs exist. These locations are discussed in greater detail in the following subsections, as project boundaries are further delineated.

Data will be acquired in two distinct phases of data collection, distinguished by their time of occurrence, duration, and sampling frequency: 1) an initial rebound phase, denoted as transient sampling; and 2) a periodic assessment of current conditions, denoted as fixed-period sampling. Transient sampling will occur at the start of the shutdown test and continue through the two 45-day phases of extraction well shutdown described in Section 2. Transient sampling will also occur during pump tests that are yet to be identified. Fixed-period sampling is analogous to the current program of semiannual monitoring, except for the addition of quarterly monitoring of TCE concentrations in selected wells to detect potential migration of the leading edge of the plume (see Section 4).

3.1.2 Results Evaluation

Contaminant distribution and water elevation data will be interpreted in the context of historical data from the site, available from the TEAD internet-based database (http://synectics.net/).

Contamination data collected during the non-operation test will be evaluated to improve understanding of the areal extent and potential movement of contamination under non-pumping conditions. Water level data will provide additional constraints on the groundwater flow model, which will improve the predictive capability of the model.

After the completion of each quarterly sample collection period, the data will be added to the database, and a letter report of findings will be presented. The purpose of the letter reports is to provide progress status identifying changes in the plume and in groundwater conditions. Upon completion of the 3-year test, the first results will have been evaluated as part of the Alternative Measures Study for groundwater at TEAD.

3.2 HYDROGEOLOGIC MONITORING

3.2.1 Transient Monitoring

When the bedrock wells are shutdown (Section 2), water levels will be monitored in specified wells as shown in Table 3-3. The geographic distribution of the wells monitored during the initial and final shutdown periods is illustrated in Figure 3-1. Temporal water levels measurements during the initial stages of rebound must be spaced closely enough to capture the rapid changes expected to occur immediately after pumping stops. A transient simulation of the proposed shutdown (Appendix A) performed using the most recent TEAD groundwater model (HEC, 2003) suggests that the maximum rate of rebound in bedrock monitoring wells within 500 feet of an extraction well is $3.3\text{x}10^{-1}$ feet per day (ft/day), and occurs within the first day after shutdown. The rebound rate declines very quickly, and becomes nearly constant at $2.0\text{x}10^{-2}$ ft/day in about 30 days. If it is stipulated that it is necessary to observe changes in head on the order of 0.02 ft, then the *maximum* allowable increment between water level measurements is approximately 1.5 hours at the start of shutdown, decreasing to about one measurement per day 30 days after shutdown.

To ensure complete characterization of rebound, however, and to take advantage of the capabilities of downhole pressure transducers transmitting data to loggers on the surface, a much higher measurement rate is proposed. The initial measurement will be taken 30 seconds after shutdown, with the measurement increments increasing according to a geometric progression with a ratio of 1.05 between successive measurements. So, the k^{th} pressure measurement will be taken at

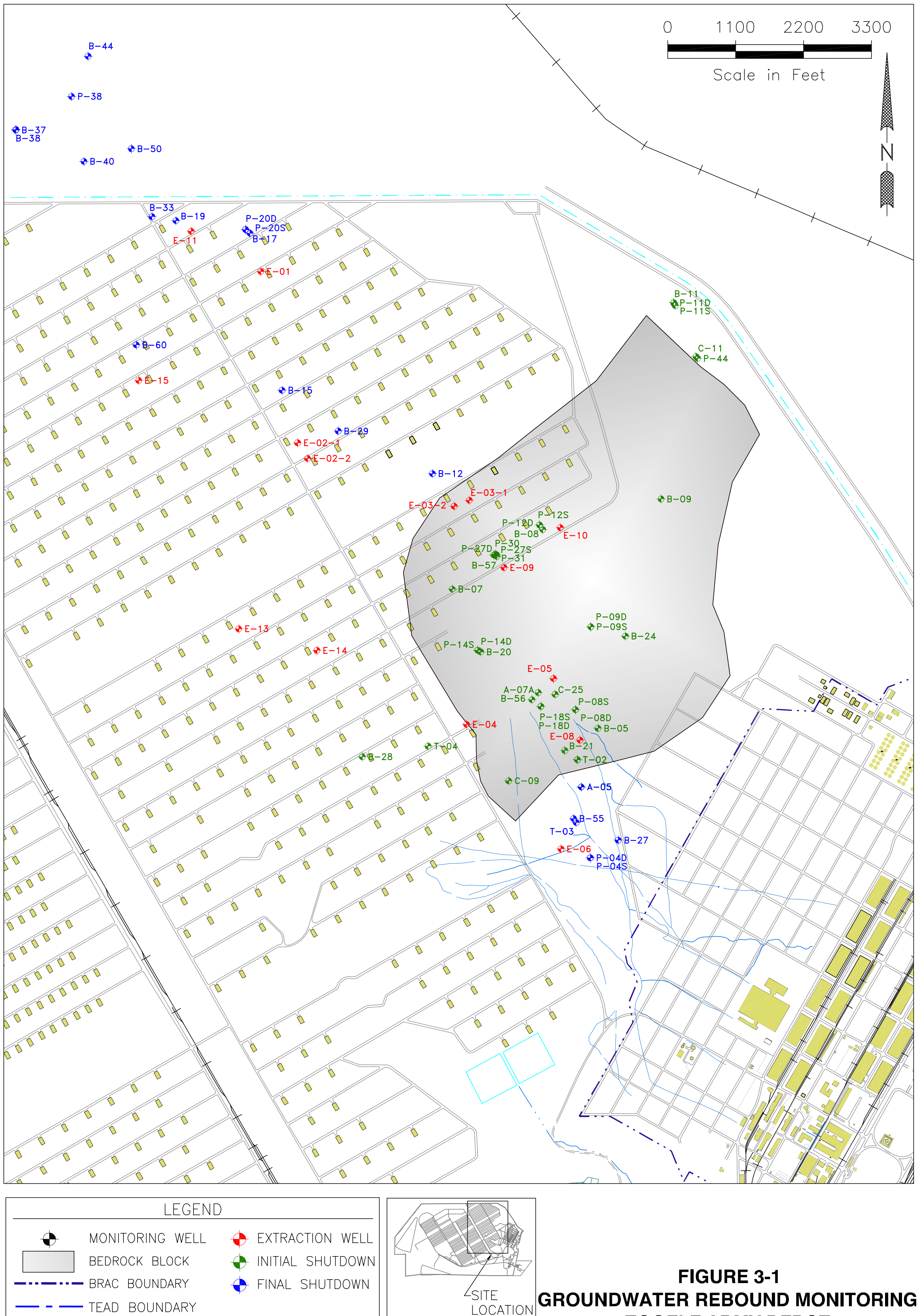


FIGURE 3-1
GROUNDWATER REBOUND MONITORING
TOOELE ARMY DEPOT

P:\Bethesda\L00000572 USACE\18600151 TEAD-GW\graphics\FIG3-1.dwg, 10/30/2003 10:35:41 AM, \\BTH\E1-07B

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Table 3-3
Transient Groundwater Elevation Monitoring

Initial Shutdown (Day 1 through 45)		
Extraction Wells	Associated Monitoring Locations	Pressure Transducers Needed
E-03-2	B-12	2
E-04	B-28, C-09, T-04	4
E-05	A-07A*, B-20, B-56, C-25, P-14S*, P-14D, P-18S*, P-18D, T-01	10
E-08	A-05, B-05, B-21, P-08S*, P-08D, T-02	7
E-09	B-07, B-24, B-57, P-09S*, P-09D, P-27S*, P-27D, P-30S*, P-30D, P-31S*, P-31D	12
E-10	B-08*, B-09, B-11, C-11, P-11S, P-11D, P-12S*, P-12D, P-44	10
	TOTAL	45
Final Shutdown (Day 46 through 90)		
Extraction Wells	Associated Monitoring Locations	Pressure Transducers Needed
E-12 (already off)	B-37, B-38, B-40, B-44, B-50, P-38	7
E-11	B-19, B-33	3
E-01	B-17, P-20S, P-20D	4
E-15	B-60	2
E-02-1, E-02-2	B-29, B-15	4
E-03-1	B-12	2
E-13, E-14	None	2
E-06	A-05, B-27, B-55, P-04S, P-04D, T-03	7
Bedrock Block	E-03-2, E-04, E-05, E-08, E-09, E-10	6
	TOTAL	37

* Location is currently a dry well. When nearby conditions indicate that water level is recovering to level measurable at this location, a time-synchronized transducer will be introduced for water level data collection.

$t_k = t_1 + 1.05t_1 + \ldots + 1.05^{k-1}t_1$. When a measurement increment of 15 minutes is reached (after about 5.2 hours), it will be held constant for the remainder of the 45-day transient monitoring period. According to this schedule, 4,371 water level measurements will be acquired in each monitored well during the 45-day period after the bedrock wells are shutdown, easily achievable with modern data logging equipment. It is assumed that a transducer is downhole in each monitoring well and transmitting prior to shutdown, and that the measured water levels prior to shutdown are consistent with historical levels recorded in the TEAD database.

The previous discussion also applies to bedrock monitoring wells greater than 500 feet away from an extraction well, and to monitoring wells screened in alluvium. The onset of rebound is delayed in bedrock monitoring wells more distant from extraction wells, but the rate of recovery is also smaller. Monitoring wells screened in alluvium have very low recovery rates in response to shutdown of the bedrock extraction wells.

At the end of the bedrock rebound test, a pressure transducer will remain in each of the six bedrock extraction wells, acquiring water level measurements at the rate of one per hour until the recovery appears to be substantially complete. Pressure transducers will be not be permanently stationed in any of the monitoring wells.

A similar approach will be used when the remaining extraction wells are shutdown (Section 2). However, rebound is expected to be faster and of smaller magnitude in alluvial sediments than in bedrock. Therefore, an initial measurement step of 30 seconds together with a ratio of 1.02 between successive measurement steps will be used. A measurement step of 15 minutes will be achieved in about 12.4 hours, and a total of 4,444 water level measurements will be logged over the 45-day period after the shutdown of the second group of extraction wells. After 45 days, a pressure transducer will remain in each of the 10 extraction wells screened in alluvium. These will acquire water level measurements at the rate of one per hour for as long as practical throughout the test period, and will only be removed during the short-term pumping of extractions wells. Pressure transducers will be removed from the monitoring wells after the first 90 days.

Table 3-3 presents the wells and piezometers for groundwater level monitoring during the bedrock rebound test, and during the subsequent shutdown of the remaining extraction wells (Section 2). The required number of pressure transducers/data loggers is also tabulated. Forty-five transducers/data loggers are needed during the bedrock rebound test; six remain downhole in bedrock extraction wells after the conclusion of the 45-day bedrock rebound test. Thirty-seven transducers/data loggers are needed in the second rebound period: six in the bedrock extraction wells, 10 in the remaining extraction wells, and 21 in monitoring wells. Sixteen transducers, one in each extraction well, remain downhole after the 45-day monitoring period following the final shutdown. TEAD and its O&M contractor will provide the transducers/data loggers and support needed to accomplish transient rebound monitoring.

Following the 90-day rebound period (i.e., after all extraction wells have shutdown and transient water level monitoring is complete) groundwater elevations within the study area will progress toward natural levels. Water level rebound will be measured daily in extraction wells using dedicated data loggers, one measurement per hour.

If hydrogeologic data gaps are identified during the review of rebound data, and in conjunction with planned Comprehensive Data Evaluation task, single-well pump tests may be proposed. This proposal does not specify these locations, however, because data gaps have not yet been identified. No future tests beyond those described in this proposal will proceed until TEAD submits plans for the tests, and the plans are approved by UDEQ.

3.2.2 Fixed-Period Measurement

Water level elevations will be collected at all site monitoring wells in conjunction with the semi-annual chemical monitoring.

3.3 CHEMICAL MONITORING

Chemical monitoring provides data needed to assess how contaminant concentrations respond to reduced pumping. Ultimately, the chemical monitoring data will be used to evaluate the degree of control exerted by the groundwater treatment system on the spatial extent of the plume and on the magnitude of contaminant concentrations within the plume. Based on expected transport rates, large-scale effects of reduced operations on the extent of groundwater contamination may not become evident until after the first six months. A comprehensive and periodically revised assessment of contamination is needed to document the nature of groundwater before the start of and during periods of reduced operations to identify when such impacts occur. The current program of semiannual monitoring yields a regularly updated evaluation of the magnitude and spatial extent of groundwater contamination at TEAD, and with minor adjustments is well suited to monitoring the plume-scale effects of reduced groundwater pumping operations.

Chemical samples will be collected using diffusion samplers in accordance with current procedures. Groundwater will be analyzed for VOCs. At the time of sample bag retrieval, a down-hole probe will be used to measure in situ pH, temperature, dissolved oxygen, and oxidation-reduction potential. These data will be used in the future alternative measures study to evaluate the groundwater conditions vis-à-vis known conditions conducive to TCE breakdown. In addition, iron and manganese concentrations reflect the oxidation state of the aquifer (each is more soluble in its reduced form). In areas were TCE is degrading anaerobically, iron and manganese levels are expected to be high. Therefore, iron and manganese will be sampled annually in extraction wells E-04, E-05, E-06, and E-08 where TCE levels are relatively high and activity most likely to be measurable.

Semiannual monitoring events may be thought of as "snapshots in time," i.e., distinct comprehensive sets of data providing a holistic image of the plume at a moment in time. By fixing the semiannual events to the same time of year as previous events, most of the expected seasonal variation may be minimized in the data comparison of current to past plume configurations. Table 3-4 presents the wells that are recommended for semiannual monitoring for VOC concentrations. It includes low-concentration wells on the perimeter of the plume and most of the wells sampled in the May 1993 sampling event.

In addition to the semiannual events, "sentinel" wells near the leading edge of the plume will be sampled quarterly and analyzed for VOCs in order to determine the need for partial re-initiation of extraction pumping. This is addressed in detail in Section 4.

The existing well network comprises multiple generations of monitoring wells, beginning with wells installed in the 1980s, and encompasses both the IWL and the Northeast Boundary TCE Plumes. Each successive generation addressed gaps in the data needed to characterize groundwater contamination. Modeling of TCE measurements from the well network, described below, indicates that the number and spatial pattern of wells in the current semiannual monitoring program is nearly sufficient to describe the limits of the combined plume, as defined by the 5 μg/L contour for TCE. However, certain additional key wells exterior to the plumes must be monitored periodically to identify the limits of the plume, especially as it expected to change during the test period.

A three-dimensional model of the commingled TCE plumes based on TCE measurements of samples from 81 wells monitored in the spring 2002 monitoring event (Kleinfelder, 2002) is presented in plan view in Figure 3-2. Only those wells monitored in the event are shown in the figure; they are indicated by letter and number (e.g., C-09). The model was constructed and rendered using kriging (Goovaerts, 1997) and visualization algorithms available in the Environmental Visualization System (EVS; C Tech Development, 2002) data analysis and visualization software. (Note: Provisions within EVS were employed to automatically estimate the spatial correlation

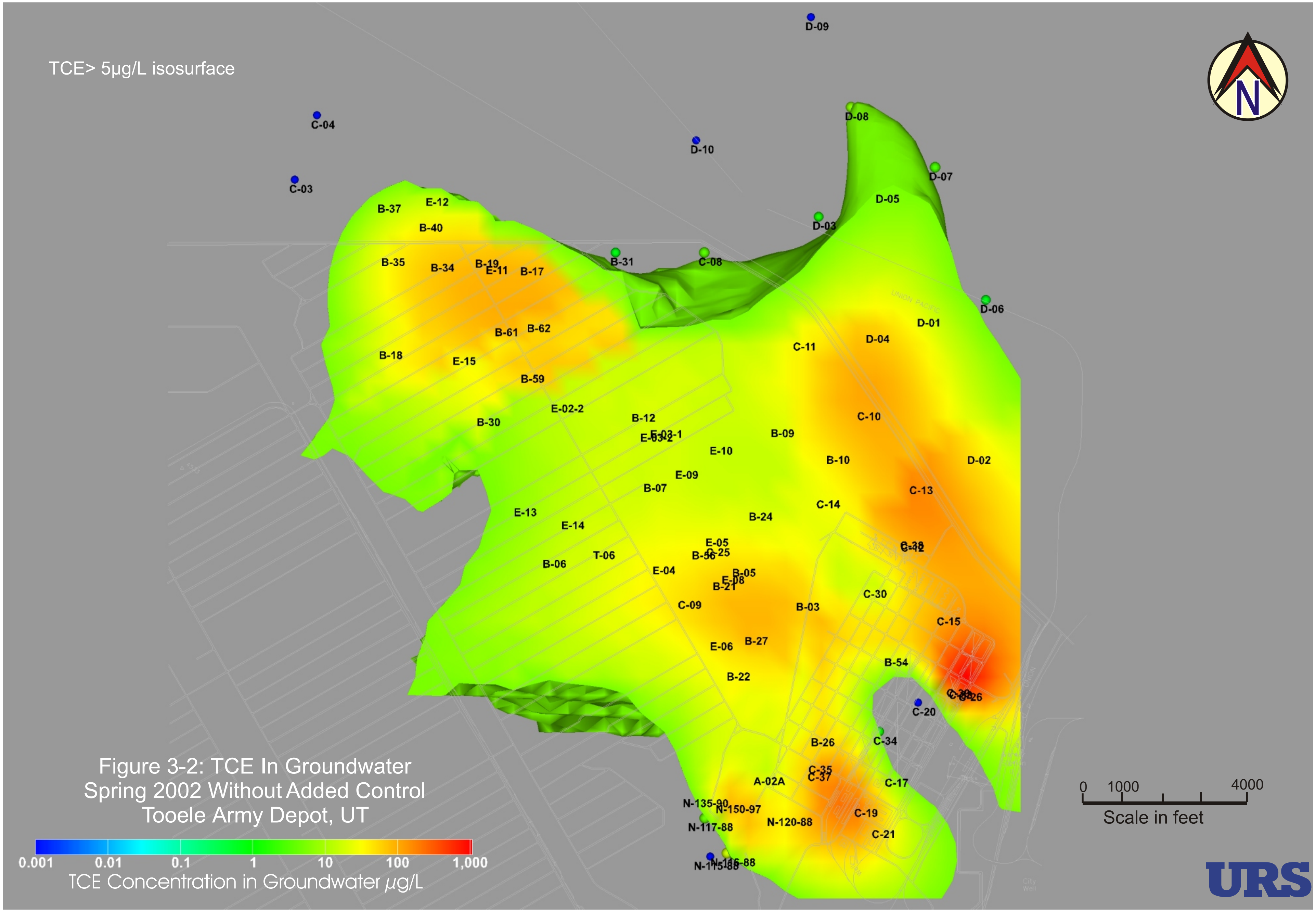

Figure 3-2: TCE In Groundwater
Spring 2002 Without Added Control
Tooele Army Depot, UT

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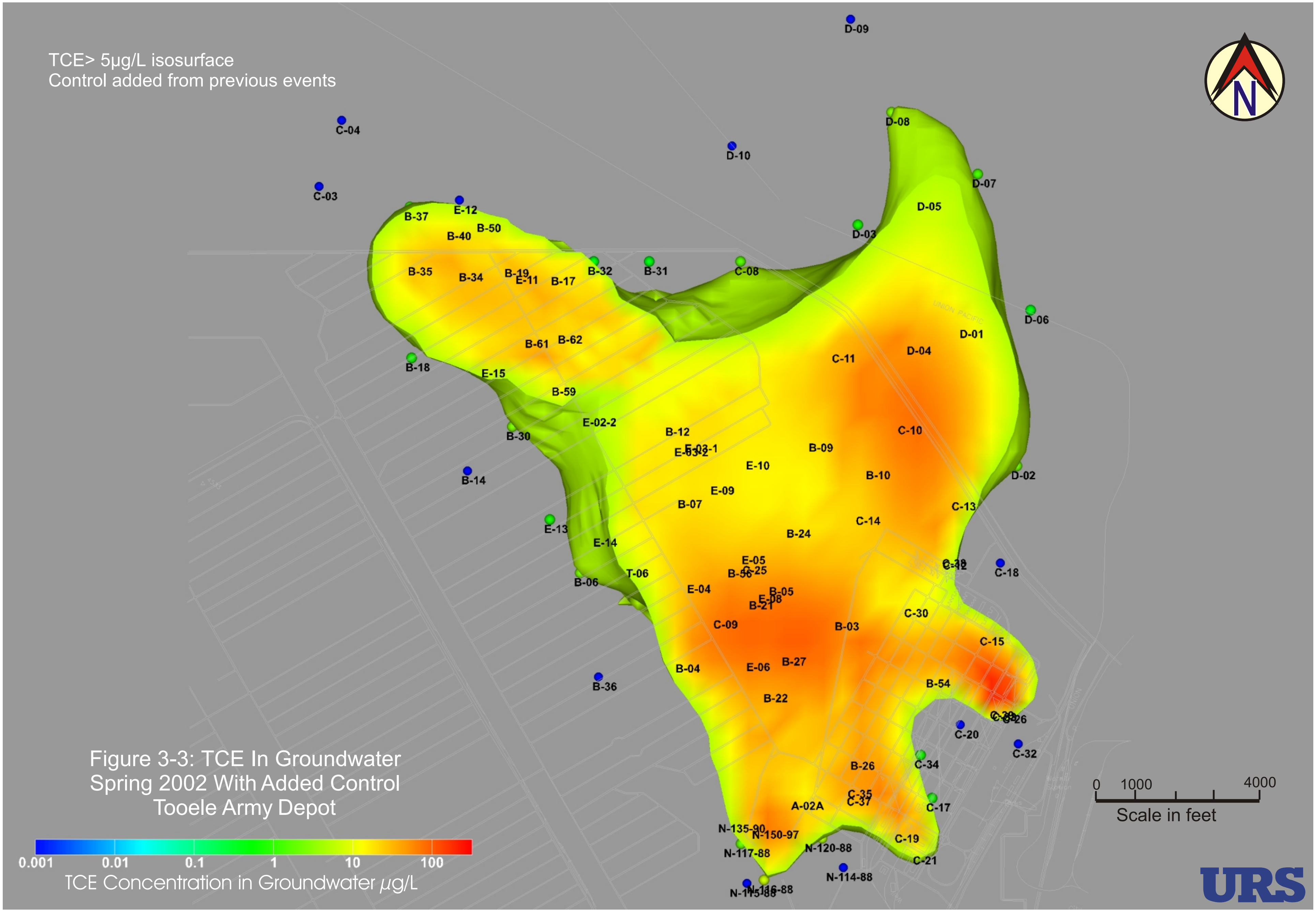

Figure 3-3: TCE In Groundwater
Spring 2002 With Added Control
Tooele Army Depot

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structure of the TCE data because a detailed analysis of spatial correlation is beyond the scope of this project at this stage.)

Review of Figure 3-2 reveals that the extent of contamination, as defined by the 5 µg/L isoconcentration surface for TCE and represented in the figure by the outer green surface, is incompletely characterized. The linear features along the eastern and southern boundaries of the model indicate where TCE concentration is extrapolated rather than interpolated; the model domain truncates the extrapolation. Had the model domain been larger, the extrapolation would have continued because there are no monitoring well data available to constrain the 5 µg/L surface. On the west, the plume is contained within the model domain. However, the bulges in the plume to the southwest of wells B-06, E-13, B-30, and B-18 are also the result of extrapolation due to the lack of well control to define the 5 µg/L surface.

To address these deficiencies, constraints on the position of the 5 µg/L isoconcentration surface were provided by augmenting the spring 2002 monitoring data with data from seven wells monitored in previous events. The resulting model of the TCE plume is illustrated in Figure 3-3. The inferred geometry of the 5 µg/L surface is more clearly delineated because extrapolation no longer occurs. Wells C-18, C-32, and N-114-88 constrain the plume model on the east and south, and B-14A and B-36 provide constraints on the west. These five wells are critical to inferring the spatial extent of the TCE plume. Although these wells may have exhibited little or no contamination in past monitoring events, and although some of them are upgradient of the plume, they are all necessary to delimiting the extent of the plume. Modeling of concentration data suggests that a significant increase of TCE concentration in any of the wells will indicate an important change in plume geometry. Accordingly, there is good reason to include them in future semiannual monitoring events, if only to verify that they continue to show no or little contamination. Wells B-50 and B-32 yield a somewhat improved delineation of the main plume in the vicinity of the northern TEAD boundary, where concern is high for changes during the test period. To delimit the plume boundary, TEAD proposes to sample in every future semiannual monitoring event wells C-18, C-32, N-114-88, B-14A, B-36, B-50, and B-32, in addition to the 81 wells included in the spring 2002 event. These wells are listed in Table 3-4.

In addition to the 88 wells used to define the plume extent, there are wells in which dramatic rebounds in TCE concentration may occur due to re-saturation of contaminated portions of the aquifer that are now dry because of groundwater extraction. The dry wells recommended for chemical analysis following re-saturation are A-03 and A-04 (south of E-06, western edge of the BRAC boundary), and B-08 (west of E-10).

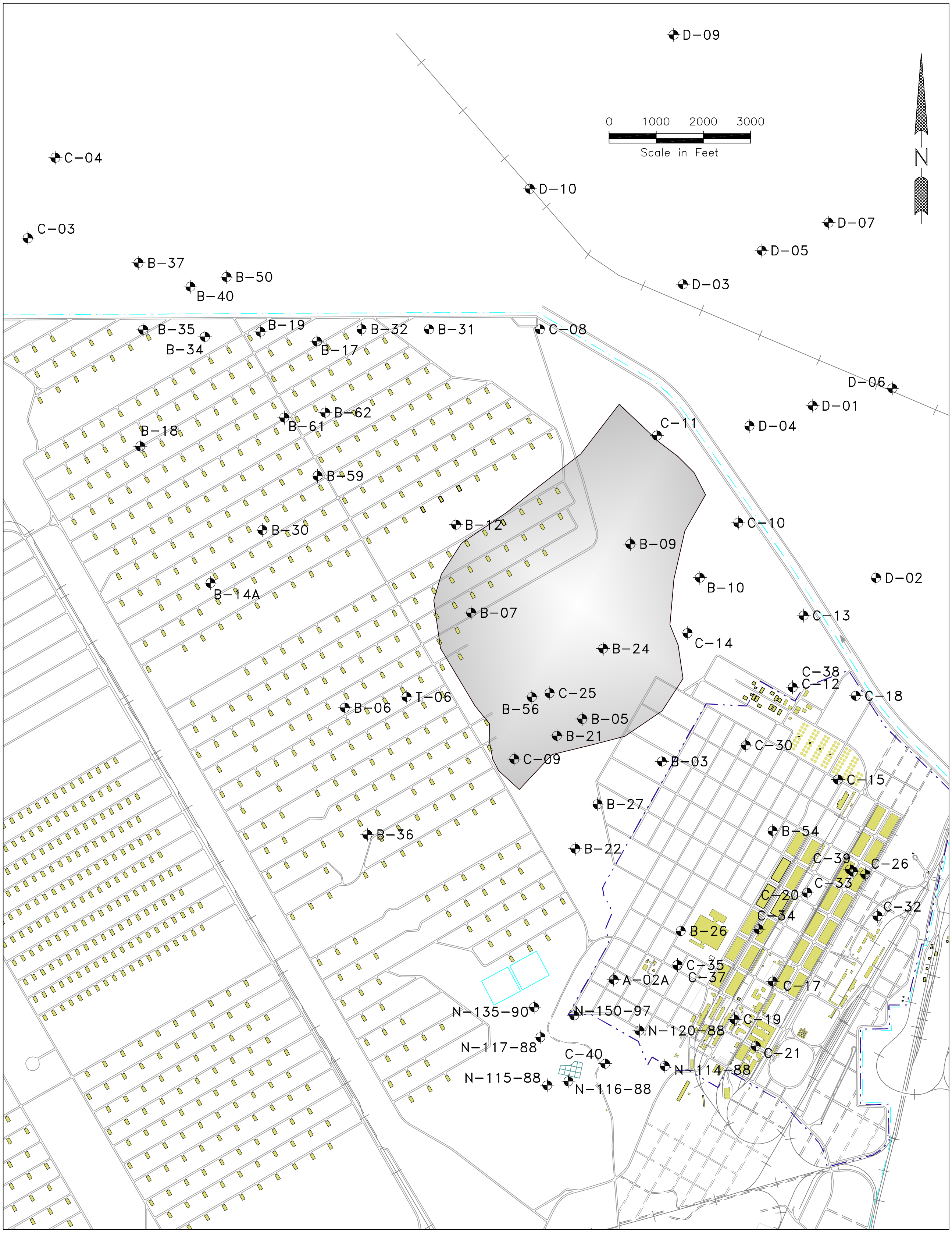
Table 3-4
Semiannual Monitoring Wells*

A-02A	B-32	C-13	D-01
B-03	B-34	C-14	D-02
B-05	B-35	C-15	D-03
B-06	B-36	C-17	D-04
B-07	B-37	C-18	D-05
B-09	B-40	C-19	D-06
B-10	B-50	C-20	D-07
B-12	B-54	C-21	D-09
B-14	B-56	C-25	D-10
B-17	B-59	C-26	N-114-88
B-18	B-61	C-30	N-115-88
B-19	B-62	C-32	N-116-88
B-21	C-03	C-33	N-117-88
B-22	C-04	C-34	N-120-88
B-24	C-08	C-35	N-135-90
B-26	C-09	C-37	N-150-97
B-27	C-10	C-38	T-06
B-30	C-11	C-39	
B-31	C-12	C-40	

* Diffusion samplers will be used in monitoring wells. Extraction wells will be sampled from sample ports at their regular exercise interval.

3.4 RESULTS EVALUATION

Monitoring data collected during the 3-year duration of the test are expected to provide information on the rate of rebound in water levels, and the subsequent changes in VOC distribution within the area affected by the groundwater treatment system. Rebound data will provide constraints on estimate aquifer properties, particularly storage, in both the bedrock block and in alluvial sediments surrounding bedrock. They will also be useful in determining where (if any) additional single well pump tests may be beneficial. Data reporting of the groundwater elevation will be accompanied by barometric pressure data recorded every 15 minutes at a Tooele city weather station,



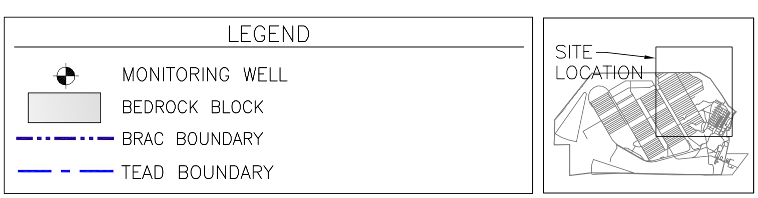


FIGURE 3-4
SEMIANNUAL MONITORING WELL LOCATIONS
TOOELE ARMY DEPOT

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available from the National Oceanic and Atmospheric Association (NOAA) on the internet at http://www.wrh.noaa.gov/Saltlake/current/meso.too.html.

Changes in contaminant distribution are expected to be useful in estimating how the plume responds in the absence of stress on the aquifer. The rate of contaminant change in the transient period may provide information on the relative effectiveness of each of the pumping wells in a local area of concern. Because there is a possibility for changes in contaminant distribution to occur, a plan has been devised to react should undesirable changes occur in the plume. This is addressed in Section 4.0.

Figure 2-1 in the previous section summarizes the schedule for initial shutdown, periodic extraction well maintenance pumping, and semiannual sampling.

Back of page; end of section

4.0 ALTERNATE PUMPING AND INJECTION PLAN

It may become necessary during the test period to restart some or all of the treatment system in order to control the leading edge of the groundwater plume. The wells, pumps, blowers, and all appurtenances of the system will be kept in working order according to the maintenance plan described in Section 5. Hence, TEAD expects that any part or parts of the system can be restarted in no more than within 2 weeks to impede downgradient migration of the plume should the leading edge of the plume appear to advance during the 3-year test. This section describes the selection of wells to be monitored during the test to detect plume migration, the monitoring frequency of these wells, the data analysis method to be employed to detect undesirable plume advances, and the pumping and injection strategy to be employed if plume migration is detected.

Although migration of contaminants may well occur within the interior of the plume in response to system shutdown, the focus of the alternative pumping and injection plan is the prevention of plume growth beyond its current areal extent. The objective is to control the VOC concentrations in groundwater at and near the leading edge of the plume to prevent downgradient expansion of the plume and possible degradation of uncontaminated groundwater.

4.1 DETECTION MONITORING WELLS

The proposed wells to be monitored for detection of plume expansion are B-16, B-34, B-35, B-37, B-40, and B-62 (Figure 4-1). The criteria used to select these wells are:

- Proximity to the plume leading edge;
- A reasonably complete recent history of chemical monitoring; and
- A position with respect to the direction of the estimated local hydraulic gradients such that plume expansion might eventually affect VOC concentrations in the well.

An additional consideration in the selection is elevation of the screened interval to ensure some measure of vertical control on detection monitoring. All data used in the selection process were extracted from the online TEAD database.

4.2 SAMPLING FREQUENCY

The detection monitoring wells will be sampled quarterly during the system shutdown. Quarterly sampling achieves a balance between the need for independent samples required for statistical analysis (described below), and for timely identification of possible plume migration; more frequent sampling may not satisfy the requirement of sample independence.

Note that each of the detection monitoring wells is also included in the list of wells to be sampled semiannually. Analytical data from the semiannual monitoring events will be used to characterize changes in contaminant concentrations internal to the plume that may occur during, and as a consequence of, the shutdown test. In addition, the semiannual data will be used to infer the plume boundary, defined by the 5 μg/L isoconcentration surface for TCE.

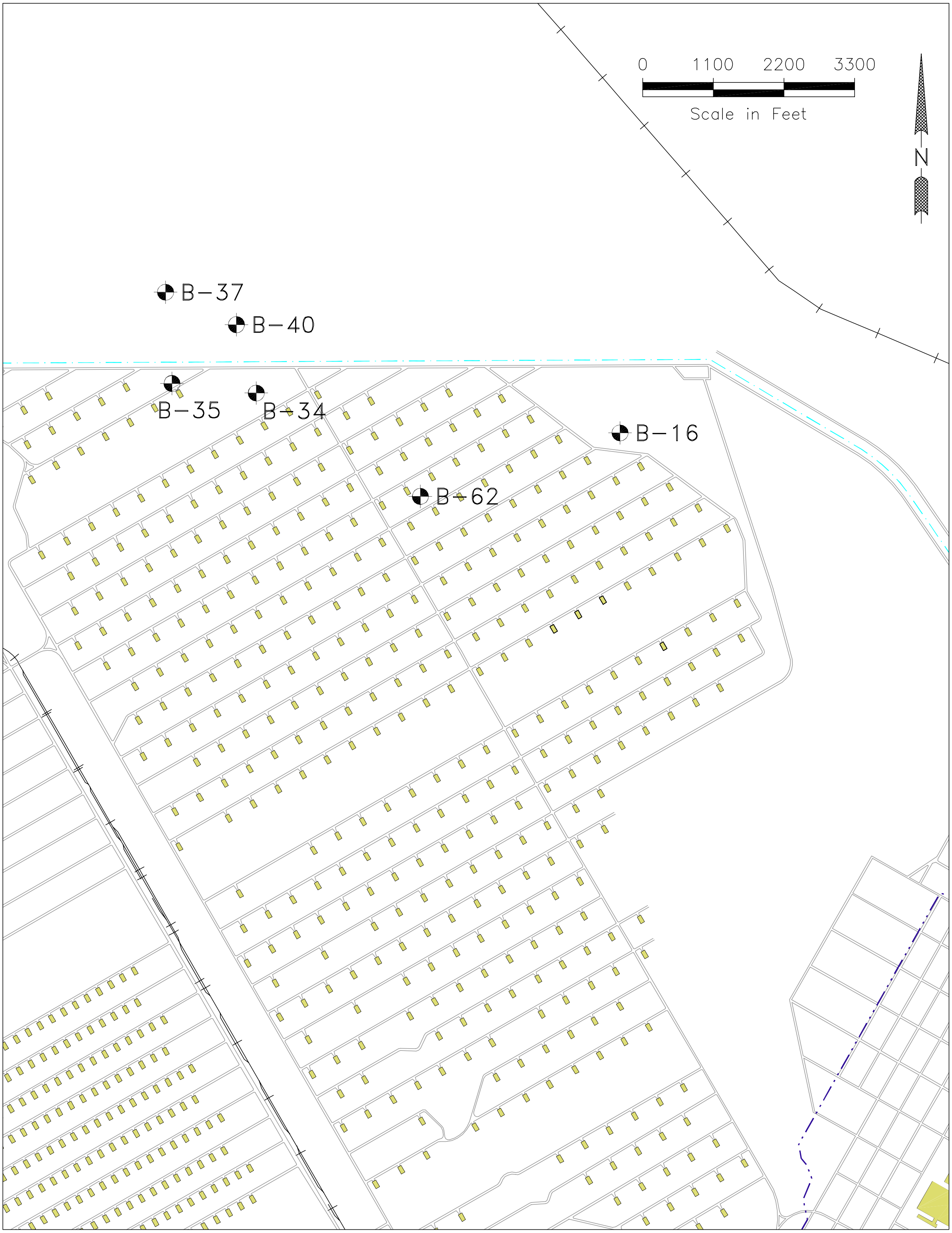
4.3 ANALYSIS OF DETECTION MONITORING DATA

The combined Shewart-CUSUM control chart method will be used to analyze the quarterly detection monitoring data. This method, described in detail in Appendix B, is widely used in landfill monitoring for timely detection of potential groundwater degradation from an upgradient contamination source, while simultaneously minimizing the probability of falsely concluding that groundwater has been degraded when it has not.

There are two components to the Shewart-CUSUM approach. The Shewart methodology focuses on the current value of the monitored constituent (TCE in this case) and its relation to historic background levels of the constituent. It is sensitive to large changes, but is less sensitive to slow, trending changes in concentration. The CUSUM methodology incorporates information from previous sampling events and is sensitive to small, gradual changes relative to historical (or 'background') concentrations. When a measured concentration exceeds either of the Shewart or CUSUM thresholds (Appendix B), it is said to be "out of control."

4.4 ALTERNATIVE PUMPING

In the event that a detection monitoring well is determined to be out of control, immediate steps will be taken to re-establish containment of the leading edge of the plume. Typical protocol used for landfills specifies that a confirmation sample be obtained before a response action is taken.



LEGEND

MONITORING WELL

BRAC BOUNDARY

TEAD BOUNDARY

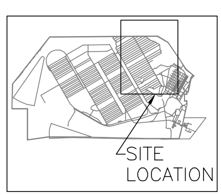


FIGURE 4-1
DETECTION MONITORING WELL LOCATIONS
TOOELE ARMY DEPOT

Back of color Figure 4-1

If an out-of-control event occurs in one (or more) of the monitoring wells, UDEQ will be notified and all available data pertinent to the event will be reviewed. A solute transport particle tracking model will be used to evaluate plume conditions. Confirmation of the out-of-control condition will be made during the next sampling round. If confirmation is received, then the proper strategy for restarting all or portions of the system will be evaluated by the project team in close coordination with UDEQ.

Back of page; end of section

5.0 SYSTEM MAINTENANCE PLAN

The system maintenance plan identifies the requirements for maintaining and optimizing the pump and treat system equipment during the 3-year test period. During the course of the test, it will be necessary to temporarily operate the pump and treat system at regular intervals as defined by the test constraints presented in Section 1.3 and by the shutdown schedule discussed in Section 2.0. The primary reason for periodic pumping is to maintain the equipment in operable condition to ensure that, groundwater extraction and treatment can be resumed within a reasonable period of time should the need arise. Reduced pumping rates and periods are used to place minimum stress on the aquifer during the shutdown test. The plan identifies maintenance activities to be performed during reduced operation. Detailed instructions on performing these activities are presented in the current system O&M plan on file at the treatment plant and are not repeated here.

5.1 DESCRIPTION OF SYSTEM

The groundwater treatment system consists of 16 extraction wells, 13 injection wells, and a treatment plant. Figure 5-1 presents a system flow schematic which shows a typical extraction well, a typical injection well, and each of the components of the treatment system including pumps, blowers, and stripper towers. (Figure 1-4 presents the geographical location of the extraction wells, injection wells, and treatment plant.) The extraction and injection wells are connected to the treatment plant by approximately 33,000 feet of buried high-density polyethylene (HDPE) pipe. The treatment plant consists of a 50,000-gallon surge tank, three 75-hp transfer pumps (two on-line and one spare), and two air stripper towers in parallel configuration. Three 40-hp air blowers (two on-line and one spare) supply air to the stripper towers. A 25-hp recirculation pump is located after the air strippers to transfer water back to the surge tank. This recirculation pump does not normally operate; instead, treated water is discharged to the piping that conveys the water by gravity to the injection wells. The head difference (driving force) from the treatment plant to the water table at the injection wells is a minimum of 165 feet (S. Kubacki, personal communication, November 2002).

5.2 REDUCED OPERATIONS

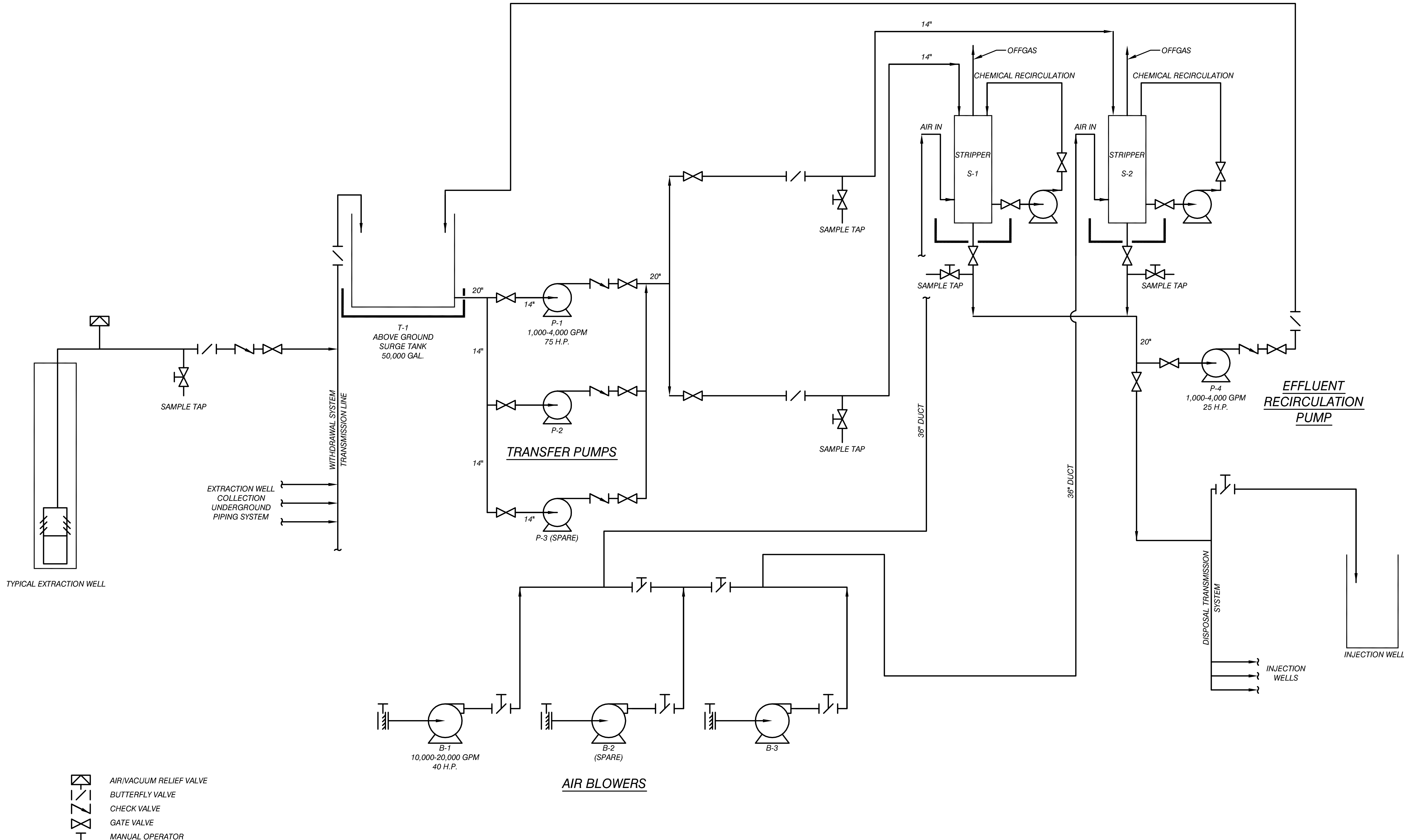
During the 3-year test period, the extraction wells and air strippers will be operated to maintain the system equipment and assure system integrity. Scaling of the air stripping tower medium during reduced operations would be extremely costly to repair and must be prevented.

Routine back-pressure tests will be conducted through-out the test period to alert operators to potential cementation and regular, low volume operation can prevent plugging of the air strippers.

Likewise, corrosion in the extraction wells may be mitigated if the system operates on a regular basis. The implementation of a corrosion control plan, now underway, will protect extraction wells from galvanic corrosion. However, current pumping operations suggest the potential for some degradation in the filter pack if pumping does not occur for extended periods. Consequently, pumping will occur periodically as described in Section 2.

Consideration was given to operating the system in batch mode by pumping each extraction well on a periodic basis, and rotating through all of the wells so that each is regularly pumped. In this mode, extracted water flows into the 50,000-gallon surge tank until the tank is full, then the water is treated and reinjected. The minimum pumping rate in each well is approximately 100 gpm and the minimum rate at which the transfer pumps can operate is 1,500 gpm, thus with one well pumping, 8 hours are needed to fill the surge tank, yet only ½ hour is needed to empty it. Because emptying the surge tank is so rapid, it appears that operating with only one extraction well at a time (i.e., in batch mode) is infeasible, unless extraction rates are increased or the number of extraction wells operated at a time is increased. Increasing extraction rates is unacceptable, because of the potential disturbance to aquifer rebound. Because of this difficulty, operation of several extraction wells simultaneously, but at the lowest possible rate and for the shortest possible duration, is preferred.

To optimize the results of the test, TEAD proposes operating the system in conjunction with the extraction well shutdown sequence described in Section 2.0. In this proposal, two alternating groups of eight extraction wells are recommended to pump at their minimum flow rate (100 gpm) continuously filling the surge tank as they operate. The surge tank will fill at 800 gpm but empty at 1,500 gpm (i.e., in about 72 minutes); a variable frequency drive (VFD) on the transfer pump must be installed to control the flow rate out of the tank. Each of the two groups of wells will extract continuously for four days, on a 180-day cycle with a 90-day lag between the two cycles. Table 5-1 (identical to Table 2-1) presents the recommended schedule for exercising the extraction wells. In essence, each extraction well will be operated for four days every six months. The anticipated effect of short duration, low-level pumping is small, and should have only minor impact on the 3-year rebound experiment. Simulations based on the most recent version of the groundwater model (HEC,



Based on Sheet M-4, Groundwater Remediation Program, TEAD, Utah;
Groundwater Remediation System P+ID, METCALF & EDDY, 1991.

FIGURE 5-1
GROUNDWATER TREATMENT SYSTEM FLOW SCHEMATIC

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2003), indicate that if the bedrock block wells are pumped at 200 gpm, only about 2 feet of drawdown will occur in nearby bedrock monitoring wells over the course of four days. Drawdown in alluvium is expected to be less because the hydraulic conductivity of the alluvium is greater than that of bedrock.

Table 5-1
Reduced Pumping Schedule

Pumping Group 1	Pumping Frequency	Pumping Group 2	Pumping Frequency
E-03-01	Day 90	E-01	Day 180
E-03-02	Day 270	E-02-01	Day 360
E-04	Day 450	E-02-02	Day 540
E-05	Day 630	E-11	Day 720
E-06	Day 810	E-12	Day 900
E-08	Day 990	E-13	Day 1080
E-09		E-14	
E-10	(180-day cycle)	E-15	(180-day cycle)

Note: 3 years equals 1095 days

The treatment plant and injection wells will also operate in reduced mode for four days according the 180-day cycle for each group of extractions wells. During these operating periods only one blower and one transfer pump will operate. The non-operating intervals between these brief periods are a concern, however, because cementation of the stripping medium may occur if water is not continuously moved through the stripper towers. Consequently, at the end of each four-day reduced-operations period, the effluent recirculation pump will recycle the final volume of treated water back into the surge tank. This water will be continuously recycled through the treatment system until the next four-day period begins. During this time, O&M contractors will recycle treated water to each tower for a week, and then switch to the other tower.

5.2.1 Inspection & Maintenance Tasks

The system will be kept in a condition ready for system restart throughout the reduced operation period. TEAD will continue to employ contract personnel who are trained to restart and operate the system. Any equipment disconnected for the purposes of servicing will be stored and maintained as necessary to allow for restarting of the system within 14 days if undesirable conditions arise as a result of the shutdown. The system will be kept in a condition ready for restart throughout the reduced operation period.

The O&M contractor will maintain a modified Preventative Maintenance Schedule to apply during the reduced operation test period. The goal of the modified schedule is to ensure that the system equipment continues to be operational and the condition of the equipment is not diminished due to lack of routine maintenance. In conjunction with URS, the contract O&M team will submit a modified preventative maintenance inspection schedule prior to system shut down.

All treatment system mechanical and electrical equipment and components that can be tested without water flow will be tested on a monthly schedule during the initial shut down. Afterwards, the entire treatment system will be tested in conjunction with the exercise of the extraction wells in accordance with Table 5-1. Several of the operating parameters will need to be optimized under the reduced pumping schedule. Such factors are addressed in Section 5.3.

5.2.2 Permit Modification

The study is pursuant to Module VI.A.3 of TEAD's Post Closure Permit, which requires submittal of a plan for additional measures to enhance the removal of hazardous constituents from groundwater every 3 years. Portions of TEAD's Post Closure Permit will require modification upon acceptance of the proposed 3-year testing. However, the proposed shut-down activities are not intended to be permanent, and Condition VI.H, Closure of Groundwater Treatment System, is not applicable at this time. The Contingency Plan for the groundwater treatment system (Attachment 6 to TEAD's Post Closure Permit, February 2002) will be revised to include any new information based on new tasks and will be updated as necessary. Current requirements will continue to be implemented where appropriate. The Plan shall continue to require that interlocks on the process equipment to prevent spills be manually activated annually (every July) to ensure proper operation. The Safety Checklist presented in TEAD's Post Closure Permit (Table VI-2) will continue to be implemented at the same frequency. Monthly reports will continue to be submitted during the test period.

5.3 SHUTDOWN PROCEDURES

Upon approval of this proposal and on a date to be determined when approval is received, each of the extraction wells will be turned off following the schedule described in Section 2.0 and in accordance with procedures in the existing O&M plan. As described in Section 5.2, the treatment plant will continue to operate throughout the 3-year test, though at greatly reduced flow during the reduced operation period. Consequently, system maintenance will remain consistent with current SOPs but with reduced chemical addition, reduced transfer pumping, reduced blower operation, and reduced power use. After the mechanical equipment is reduced to one operating pump over an extended period, further reduction of electrical use can be achieved through addition of a VFD. The capital cost of VFDs will have to be compared to the potential electrical cost savings over the time period of reduced operations before a recommendation for their installation can be made.

A reduced-operations SOP will be developed by the O&M contractor in conjunction with URS for the treatment system (extraction wells and treatment plant) once this reduced pumping plan is accepted by UDEQ. Thereafter, the chemical and physical operational parameters can be adjusted based on the reduction of operating extraction wells. At reduced operations there will be adjustments to:

- Air to water ratio, which affects blower operations,
- Volume of water conveyed to stripper, which affects the amount of sodium hexametaphosphate added for scale control, and
- Flow, which affects the number of pumps and possibly the number of stripper towers. Reduction in flow also may affect power requirements.

During the time that the treatment system is in recycle mode, procedures must be in place to assure that extraction wells are not operating and the surge tank does not overflow. According to the "Tooele Army Depot, Groundwater Treatment Plant Site Health and Safety Plan," February 2002, the following procedures should be followed:

- The influent control valve (FCV 50) will be closed manually to ensure that no groundwater can enter the surge tank.
- All extraction well VFDs will be turned to the "Off" position with the hand/off/auto switch located inside the VFD cabinets. The extraction well VFDs are labeled to match their corresponding extraction well (e.g., E-1, E-2.1, etc.).
- The treatment system will continue to operate (on one tower and blower) until all of the extracted groundwater is treated.
- The blower will be turned off.

- The effluent recirculation pump will recycle treated water into the surge tank, and this water will be used to maintain the tower medium.

5.3.1 Optimization Procedures

Once the reduced flow is established, the operators will assess ways to optimize the treatment system. Table 5-2 summarizes the parameters that will require addressing. The assessment can be conducted in conjunction with URS once the minimum and maximum reduced flow operations are determined by the O&M contractor. Emphasis is placed on alternating use of pumps and blowers on a regular basis to keep them exercised, and alternating stripping towers to keep towers free of particulate cementation (Steve Kubacki, personal communication, December 2002).

Table 5-2
Reduced Operations Optimization

Reduced Flow Effect	Benefit	Action
Reduce number of transfer pumps	Reduce O&M cost	Calculate maximum flow during reduced operations and select one pump to operate; if pump is oversized for reduced flow, consider adding a VFD to reduce amperage to existing pump motors; alternate use of all three pumps on a cyclical basis to keep pumps exercised.
Reduce amount of chemical additive	Reduce O&M cost	Prorate addition of chemical based on reduced groundwater flow; also consider reduced water chemistry concentrations in calculation.
Reduce number of blowers	Reduce O&M cost	Multiply required air/water ratio by reduced flow to determine the number of blowers to operate.
Alternate use of stripping towers	Reduce O&M cost of idle tower, and cost of chemical additive	During reduced flow, direct hydraulic flow through one tower to maximize agitation of particles to prevent settlement; alternate flow on a regular basis to keep towers free of scale and particle settlement; alternating flow also will keep the potential of biological growth from occurring (if degradable organic material exist in air and/or groundwater) on tower media.
Reduce blower air output	Reduce O&M cost	If a blower is oversized for reduced operation, consider adding a VFD to reduce amperage to existing blower motor to reduce electrical costs; evaluate water chemistry and determine minimum air for organic stripping.

The current configuration of blowers (Figure 5-1) has the valves downstream of the blowers directing air to one or both towers. Because all groundwater will be treated in one tower, all airflow will be directed to that tower. Because the towers will be used alternately, valves will have to be adjusted to direct air to one tower only.

5.3.2 Cathodic Protection of Extraction Wells

During current pumping operations, well plugging is prevented by continuous operation of the pumps. This assures conveyance of fine particles through the well screen, that otherwise may precipitate in the well screen slots. Precipitates have not been a problem at the extraction wells. However, at some wells, corrosion has created perforations at or above the well screen and weakened the structural integrity of some extraction wells. This has caused the sand pack surrounding the well casing and screen to flow through the enlarged perforations caused by the corrosion. The sand has caused damage to the pump. Instances of flowing sands would damage the pumps and eventually clog the well, making it ineffective for extraction of groundwater. As a result, a plan has been developed for installing cathodic protection at every extraction well (Associated Corrosion Engineers, 2002).

The primary purpose of cathodic protection is to maintain the integrity of a well. An ancillary benefit of cathodic protection is that it will mitigate precipitation of solids at the well screen slots when pumping is reduced or shut down (J. Hanck, personal communication, November 2002). The plan calls for installing sacrificial anodes in the extraction wells to retard corrosion of the well screen and the carbon steel material to which the well screen is attached (Associated Corrosion Engineers, 2002).

As of March 2003, cathodic protection has been installed in extraction wells E-04, E-05, E-06, E-08, E-09, and E-10. The remaining extraction wells will be protected prior to the approval this proposal or any system shutdown. The cathodic protection system includes a rectifier that feeds a direct current at a prescribed voltage to the graphite anodes (sacrificial anodes). Once the system is installed, these rectifiers will be adjusted to minimize corrosion of the screens and surrounding carbon steel material. Once constraints are established for long-term use (projected to be greater than 40 years at continuous usage), periodic inspection of the cathodic protection system will be conducted as part of system maintenance. Periodic adjustment of the rectifier may be necessary. The performance requirements, inspection checklist, and adjustment procedures will be provided to the O&M contractor by the corrosion expert responsible for installation of the cathodic protection, and will be incorporated into the standard O&M procedures. Additionally, an 8-hour training session will be provided by the corrosion expert, at which time the O&M contractor will learn the proper maintenance of the cathodic protection. Performance is measured by comparing operational parameters recorded at the panel and include, but are not limited to, flow, pressure, temperature, and amperage.

During reduced operations when extraction wells are operating only periodically, the cathodic protection will be maintained in accordance with procedures that will be provided by the corrosion expert. During the reduced operation period, ground current measurements will be made to adjust the external cathodic protection. Cathodic protection must be operated and maintained continuously for all wells including those that are pumping and those that may not be pumping under reduced operating conditions.

5.3.3 System Shutdown Notifications and Reporting

In the event that the system is shut down entirely, a schedule will be submittal to UDEQ and EPA, which will present the shutdown date. A detailed report will be submitted to UDEQ and EPA summarizing the shut down activities and will include any deviations from this work plan. Procedures for shut down are provided in the existing O&M plan, and would be presented as part of notification to UDEQ and EPA.

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APPENDIX A

Aquifer Response to Shutdown

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APPENDIX A: AQUIFER RESPONSE TO SHUTDOWN

One of the objectives of the 3-year shutdown test is to obtain information about the hydraulic character aquifer system at TEAD that can be used to improve the numerical model of the system. Aquifer rebound during the shutdown test was simulated to compare modeled response of the aquifer behavior to observed behavior. Assuming that the model reflects the best current understanding of the aquifer, comparing the observed transient changes in water levels with predicted changes will indicate how accurately the model reflects the true hydraulic character of the system. Discrepancies between observations and predictions are the basis for refining and improving the model.

The simulations were performed using the latest flow model (HEC, 2003) supplied to URS by Jon Fenske on April 10, 2003. None of the hydraulic properties specified in the model were modified. The only modification to the model was to simulate the two-stage of shutdown of the extraction system as outlined in Section 2 of this proposal by running the model in transient mode, using as starting heads the simulated steady-state heads reported in HEC (2003). The simulation was run for a period of three years.

The difference between a steady state and transient run for the model is that the transient mode specifies storage; the hydraulic properties are identical in every other respect. The current model contains order-of-magnitude estimates for storage for various regions of the aquifer. Rebound can be simulated by specifying when the extraction wells are shutdown and when the simulated water elevations are to be written to a file, thereby allowing the model to run in transient mode.

Rebound behavior is sensitive to aquifer storage as specified in the model. Transient behavior in an aquifer can be estimated using the ratio of hydraulic conductivity to storage. For a fixed hydraulic conductivity, changing the storage affects the timing of rebound. Increasing the storage will increase the time needed to achieve a specified rebound, decreasing the storage will decrease the time. Once the system is shutdown, observed rebound curves may yield very useful constraints on the magnitude of storage in various regions of the aquifer.

An important component of the shutdown test is the 45-day bedrock rebound test initiating the system shutdown (Section 2). One of the reasons for shutting down the bedrock block wells first is to establish whether E-03-2 is screened in the bedrock block (or bedrock block shell) or in alluvium. In the current model E-03-2 is screened in the bedrock block. Rebound in wells near E-03-2 is presented in Figure A-1. The simulation results indicate that very little recovery (about 2 feet) is expected after 45 days in B-12, screened in alluvium, in comparison with P-12D and B-07 (about 10 feet), both of which are screened in bedrock. Locations P-12D and B-07 are farther from E-03-2 than B-12, and they are also influenced by other nearby extraction wells (E-09 and E-10). If higher rebound is observed in B-12 during the first 45 days of the test, it may indicate that E-03-2 is screened in alluvium rather than bedrock. The onset of the second stage of shutdown is indicated in the figures by the closely spaced symbols at Day 45, i.e., the start of a modeling stress period coinciding with the shutdown of the remaining bedrock wells.

The response displayed in Figure A-2 also illustrates the poor hydraulic connection between alluvium and bedrock as is apparent in water level maps. Wells B-28, and B-20 are roughly equidistant (in the horizontal plane) from E-04, but B-28 (screened in alluvium) exhibits virtually no recovery in 45 days; B-20 shows about 8 feet of recovery. Together, Figures A-1 and A-2 suggest that shutdown of the bedrock block wells will have a minimal effect on alluvium wells during the initial 45 day shutdown.

Figure A-3 illustrates the effect on rebound of distance from extraction wells. All illustrated wells are in the bedrock and in model layer 6. B-05 is the nearest to an extraction well, P-11D the most distant. The added distance introduces a delay between the start of shutdown and noticeable rebound. The delay is most pronounced for the most distant monitoring point at P-11D. As noted above, changing the storage properties of the bedrock block will affect the magnitude of the delay. Increasing storage increases the delay; decreasing storage reduces it.

Similar rebound is expected in the bedrock for a similar horizontal location, regardless of vertical location of the screened interval, as illustrated in Figure A-4. P-27S and B-57 are near one another in map view, but the elevation of their screened intervals differs by about 280 feet (both have a screened interval of 10 feet). The simulated rebound in each is very similar in shape and magnitude (a bit more than 10 feet).

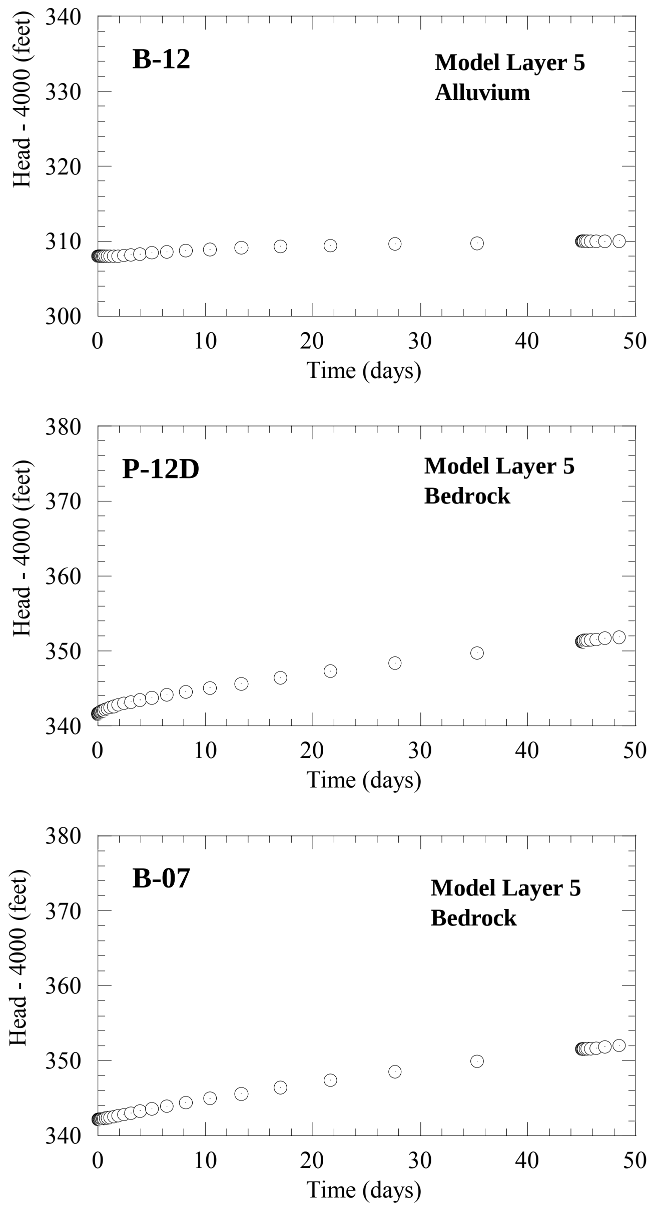


Figure A-1. Simulated water level recovery in a well screened in alluvium (B–12) compared to recovery in wells screened in bedrock (B-07 and P-12D).

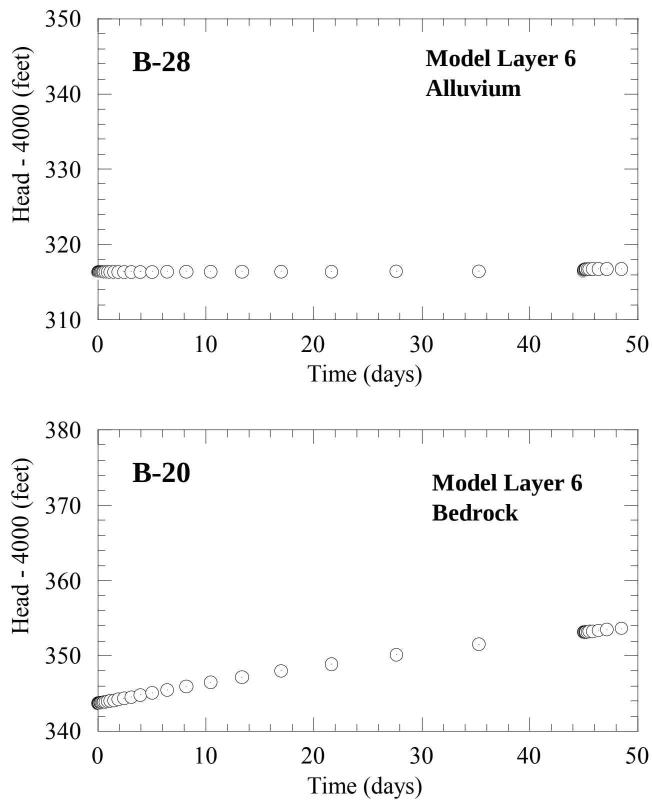


Figure A-2. Simulated water level recovery in a well screened in alluvium (B–28) compared to recovery in wells screened in bedrock (B-20 and B-58).

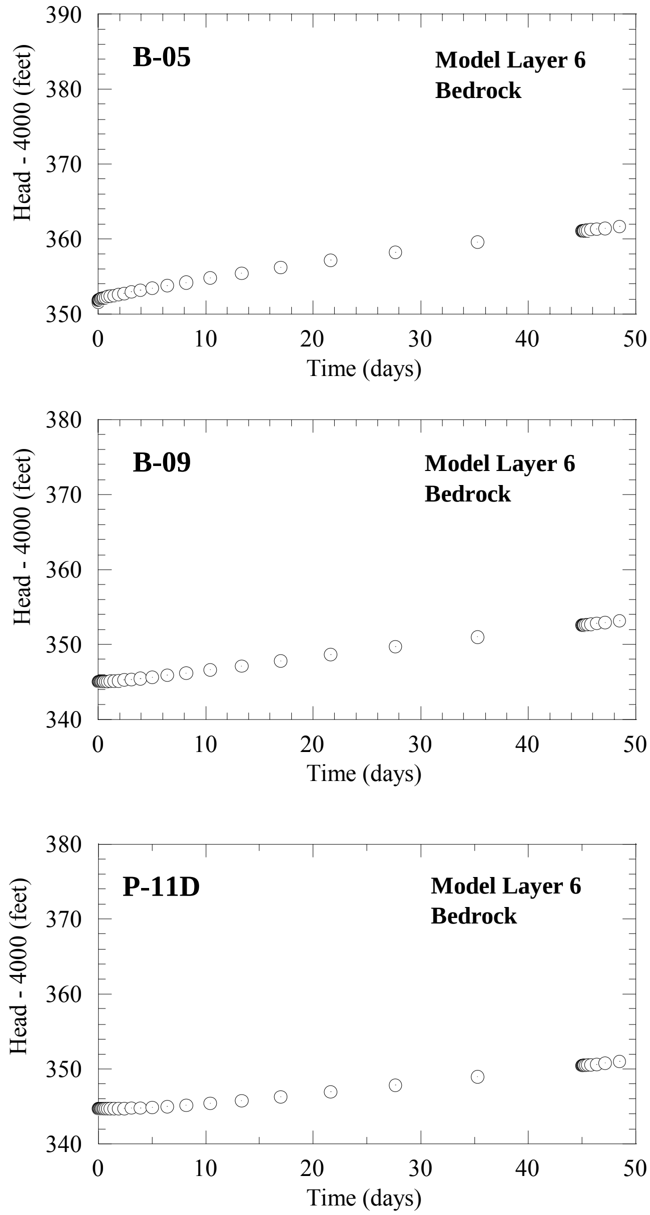
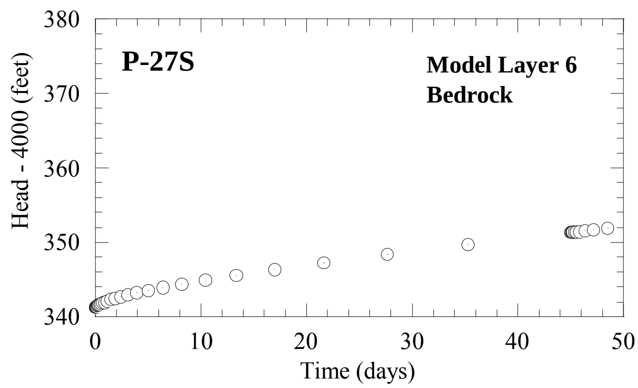


Figure A-3. Simulated water level recovery in wells screened in bedrock and within the same model layer, but at different horizontal locations.



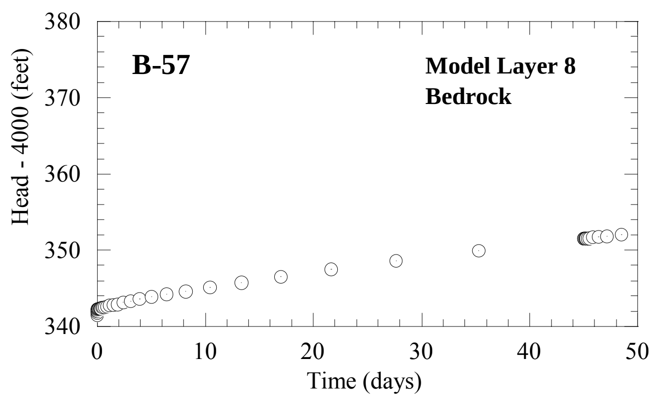


Figure A-4. Simulated water level recovery in wells screened in bedrock in differing model layers, but at a similar horizontal (map view) location.

APPENDIX B

Control Chart Analysis

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APPENDIX B: CONTROL CHART ANALYSIS

B.1 OBJECTIVE

The objective of statistical groundwater detection monitoring during the test is the timely detection of potential groundwater degradation due to downgradient migration of the TCE plume, while simultaneously minimizing the probability of falsely concluding that groundwater has been degraded when it has not. Using recent data, threshold limits for TCE are established for wells B-31, B-37, E-12, and C-08 so that any future change in groundwater chemistry downgradient of the plume can be detected. Future analytical measurements that cause the threshold to be crossed are taken to indicate downgradient movement of the plume, requiring the reinitiation of measures to control plume migration.

B.2 DESCRIPTION

The detection monitoring program is based on intrawell comparisons, in which monitoring measurements of a chemical constituent are compared to the history of measurements within a well, rather than by comparing measurements between wells. Intrawell comparisons are useful when there is a clear difference between groundwater chemistry upgradient and downgradient of a specified spatial boundary, in this case the 5 μg/L isoconcentration surface for TCE. The current (for purposes of discussion, spring 2002) position of the surface at the leading edge of the plume is similar to its position in 1993, before the start of groundwater treatment at TEAD. Fluctuations in the position of the surface can be ascribed to the combined effects of natural variability, random measurement error, and the set of measurements used to infer the character of the isoconcentration surface. Upgradient of the boundary, groundwater is contaminated by TCE; downgradient, groundwater is assumed to be free of TCE contamination.

The approach selected for analysis of the detection monitoring data obtained during the test period is the Shewart-CUSUM control chart method, originally developed for statistical quality control of manufacturing processes (Bowker and Lieberman, 1972), and widely applied to groundwater monitoring at landfills (Gibbons, 1994). There are two components to this approach. The Shewart methodology focuses solely on the current monitoring value of a monitored groundwater constituent (in this case, TCE) and its relation to historic background levels of the constituent; it is sensitive to large and sudden changes, but less sensitive to slow, trending changes in concentration. The CUSUM methodology incorporates information from previous measurements, and is sensitive to small, gradual changes relative to background concentrations. Referenced documents American Society for Testing and Materials (ASTM) PS 64-96, USEPA (1994), Gibbons (1994), and Gilbert (1987) describe the approach in detail.

Gilbert (1987) identifies the underlying assumptions to the Shewart-CUSUM method: the data must be independent, normally distributed, and have constant mean and variance. These conditions must be considered as part of the method application. The TCE concentration data may not meet these conditions. If the data are normally (or lognormally) distributed and serial correlation is not large, then the proposed method will be adequate. However, if autocorrelation is high (e.g., due to seasonal lag), then Gilbert recommends using a time series method by plotting the residuals of the measurements (the residual is defined as observed value minus the value estimated using a stochastic model). The stochastic model is described more fully in Box and Jenkins, 1976.

B.3 METHODOLOGY

Each well is considered independently of the others. Background (or historical) levels are computed for TCE in the well. Background in a well is taken as the mean TCE concentration in the well, computed from the eight most recent sampling events prior to the start of the shutdown test. The eight background samples are assumed to be independent and Gaussian with fixed mean and variance. Independence is assumed to be met by using background data collected no more frequently than quarterly. The Gaussian assumption will be checked using the Shapiro-Wilk hypothesis tests (Conover, 1999; Hintze, 2001; Gilbert, 1987); if necessary, the background data will be transformed (e.g., using logarithms) to satisfy the Gaussian assumption. If this fails, the residuals will be subjected to testing, as described in the immediately preceding section.

The background level of TCE in each well is summarized by the sample mean $\bar{x}$ and the sample standard deviation $\boldsymbol{s}$, computed from background measurements for the analyte using the usual expressions for $\bar{x}$ and $\boldsymbol{s}$ (see, for example, Gibbons, 1994). Note that $\bar{x}$ and $\boldsymbol{s}$ for TCE are expected to vary from well to well.

Each new TCE measurement in a well is compared to threshold limits for the well to assess whether the leading edge of the plume has advanced downgradient. The procedure is as follows:

- Denote the new TCE measurement taken at time t_i by x_i (i = 1 corresponds to the first sampling round after the start of the shutdown test; subsequent detection monitoring samples are taken quarterly).
- Compute the standardized value $z_i = (x_i - \bar{x})/s$.
- At each time t_i, compute the cumulative sum $S_i = max[0, (z_i-1)+S_{i-1}]$.
- Plot both z_i and S_i versus t_i, constructing the Shewart-CUSUM control chart.

An "out of control" concentration is indicated if, for the first time, either z_i is greater than 4.5 or S_i is greater than 5.0. The thresholds z_i equal to 4.5 and S_i equal to 5.0 are, respectively, the Shewart and CUSUM thresholds.

The protocol for landfills calls for confirmation sampling in the event an analyte is determined to be out of control (EPA, 1992; Gibbons, 1994). If TCE is assessed to be out of control in a well, immediate measures will be taken to reassert hydraulic control of the plume (see Section 4).

The procedure described above uses the normalized TCE concentration z. It is possible, however, to express the threshold for TCE in a well in terms of the original concentration by application of the formulas:

$$SCL = \bar{x} + 4.5s \text{ and } CCL = \bar{x} + 5s$$

Here, ***SCL*** denotes the Shewart control limit and ***CCL*** denotes the CUSUM control limit. Similarly, the S_i can be expressed in terms of concentration by calculating $S_i' = \bar{x} + s\, S_i$.

A hypothetical example using well B-37 illustrates the Shewart-CUSUM procedure. Table B-1 lists the eight most recent TCE measurements available in the TEAD internet database for B-37. The sample mean for these data ($\bar{x}$) is 4.3 and the sample standard deviation (s) is 1.1. A hypothesis of normality cannot be rejected at the 90 percent significance level using any of the Shapiro-Wilk, Anderson-Darling, Kolmogorov-Smirnov, or D'Agostino tests.

Table B-1
Eight Most Recent TCE Measurements in B-37

Well ID	Sample Date	Measured TCE Concentration (μg/L)
B-37	7-Jun-99	3.0
B-37	29-Nov-99	3.2
B-37	26-Jun-00	4.5
B-37	3-Jan-01	5.8
B-37	16-May-01	5.9
B-37	4-Oct-01	3.2
B-37	27-Mar-02	4.6
B-37	10-Dec-02	4.3

The sample statistics $\bar{x}$ and $\boldsymbol{s}$ were used to perform two probabilistic experiments, the first to illustrate the case where downgradient migration of the plume does not occur during the shutdown test, the second to illustrate the case where migration does occur. Table B-2 lists simulated measured TCE concentrations for quarterly samples assuming that the shutdown test began immediately after the fall 2002 sampling event. The simulated TCE concentrations are independent Gaussian random variables selected from a larger population generated to have mean (i.e., the true mean μ) 4.3 and standard deviation (σ) 1.1. Thus the simulated concentrations are independent random variables from the same distribution as the background samples and represent the case where plume migration does not occur. Table B-2 also lists the computed values $\boldsymbol{z_i}$, $\boldsymbol{z_{i-1}}$, and $\boldsymbol{S_i}$. The quantities $\boldsymbol{z_i}$ and $\boldsymbol{S_i}$ are plotted in Figure B-1(a). Note that $\boldsymbol{z_i}$ never exceeds 0.8, and that $\boldsymbol{S_i}$ never differs from 0. All future measurements are in control, and no plume movement is detected.

Table B-2
Hypothetical Shewart CUSUM Calculations, No Detected TCE Increase

Hypothetical Sampling Event	Sampling Period, *i*	Simulated TCE Concentration (μg/L)	z_i	z_i-1	S_i
Winter 2002	1	2.4	-1.6	-2.6	0
Spring 2003	2	3.5	-0.7	-1.7	0.0
Summer 2003	3	2.3	-1.7	-2.7	0.0
Fall 2003	4	5.0	0.6	-0.4	0.0
Winter 2003	5	5.1	0.7	-0.3	0.0

Spring 2004	6	3.5	-0.7	-1.7	0.0
Summer 2004	7	5.3	0.8	-0.2	0.0
Fall 2004	8	4.3	0.0	-1.0	0.0

As a counter example, Table B-3 lists the simulated measured TCE concentrations for the hypothetical case in which the leading edge of the plume advances downgradient. In this case, a pattern of systematically increasing TCE concentration was simulated by first generating an independent Gaussian random variable as above, and then adding to it the quantity ***is/2***, where ***i*** is the sampling period and ***s*** is the sample standard deviation computed from background. This addition effectively transforms the results so that they no longer conform to the sample distribution. The Shewart-CUSUM calculations are shown in Table B-3, and the results plotted in Figure B-1(b). In this example, the Spring 2004 sample is out of control because z_s equals 4.8 and exceeds the Shewart threshold of 4.5. Note the immediate response to an unusually high concentration with respect to background. In addition, note that although the normalized concentration zi decreases after the fifth sampling event following the start of shutdown, S_i continues to increase and stays beyond the threshold of S_i equals 5.0 after the sixth sampling event.

Table B-3
Hypothetical Shewart CUSUM Calculations, Detected TCE Increase

Hypothetical Sampling Event	Sampling Period, i	Simulated TCE Concentration (μg/L)	zi	zi-1	Si
Winter 2002	1	4.9	0.6	-0.4	0
Spring 2003	2	5.7	1.2	0.2	0.2
Summer 2003	3	6.0	1.4	0.4	0.7
Fall 2003	4	3.9	-0.4	-1.4	0.0
Winter 2003	5	9.8	4.8	3.8	3.8
Spring 2004	6	8.1	3.3	2.3	6.1
Summer 2004	7	7.5	2.8	1.8	8.0
Fall 2004	8	10.6	5.5	4.5	12.5

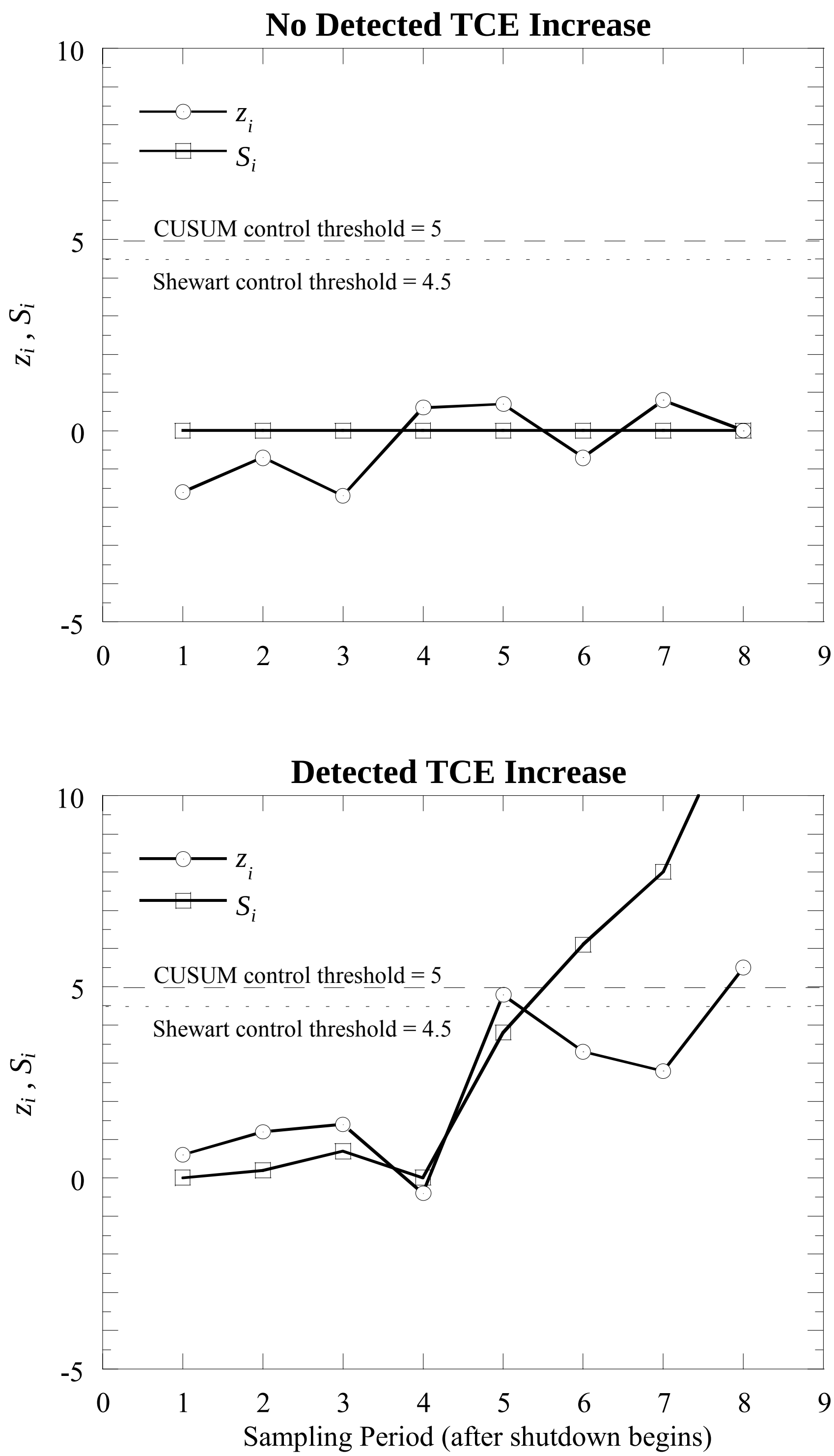

Figure B-1. Hypothetical examples illustrating Shewart CUSUM control charts for (a) the case of no plume movement, and (b) plume movement.

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